Appendix H
GROUND WATER MODELING REPORTS

I. Osceola Regional Model

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II. Glades, Okeechobee, and Highlands (GOH) Model

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I. OSCEOLA REGIONAL MODEL

Purpose and Scope

This section describes the development and calibration of a three-dimensional ground water flow model of the Upper Floridan aquifer (UFA) in Osceola County. Portions of the surrounding counties were used to help minimize the effects of the boundary conditions in the Osceola County Area.

Figures H-1 and **H-2** depict the location of the study area. The study area is located in east-central Florida.

Major Aquifer Systems

There are two major aquifer systems within the study area: the Surficial Aquifer System (SAS) and the Floridan Aquifer System (FAS). Both aquifers are laterally continuous throughout the study area. **Figure H-3** provides a generalized hydrogeologic column of the study area.

In addition to the reconnaissance work associated with this project, the following is a listing of the major reports used to develop the hydrogeologic framework: Barcelo (1998), CH2M Hill (1993), Dames and Moore, Inc. (1988), Geraghty and Miller, Inc (1977), Planert and Aucott (1985), PBSJ (1987), PBSJ (1990a), PBSJ (1990b), PSI (1994), Shaw and Trost (1984a), Shaw and Trost (1984b), Tibbals and Grubb (1982), and Yobbi (1996).

The SAS is composed of low to moderately permeable clastic and carbonate sediments. Ground water in the SAS can exist under confined, semi-confined, or unconfined conditions.

The intermediate confining unit (ICU) consists of fine clastic and carbonate sediments, which acts as an aquitard. In this report, the top of the ICU corresponds with the top of the Hawthorn Group. In the study area the top of the Hawthorn Group is identified by an increase in content of green clay.

The FAS underlies the ICU within the study area. Schiner (1993) separates the FAS into 3 separate units: the UFA, the middle confining unit (MCU), and the Lower Floridan aquifer (LFA). The following formations make up the FAS:

- UFA - Ocala Limestone and upper portion of the Avon Park Formation

- MCU - lower portion of the Avon Park Formation
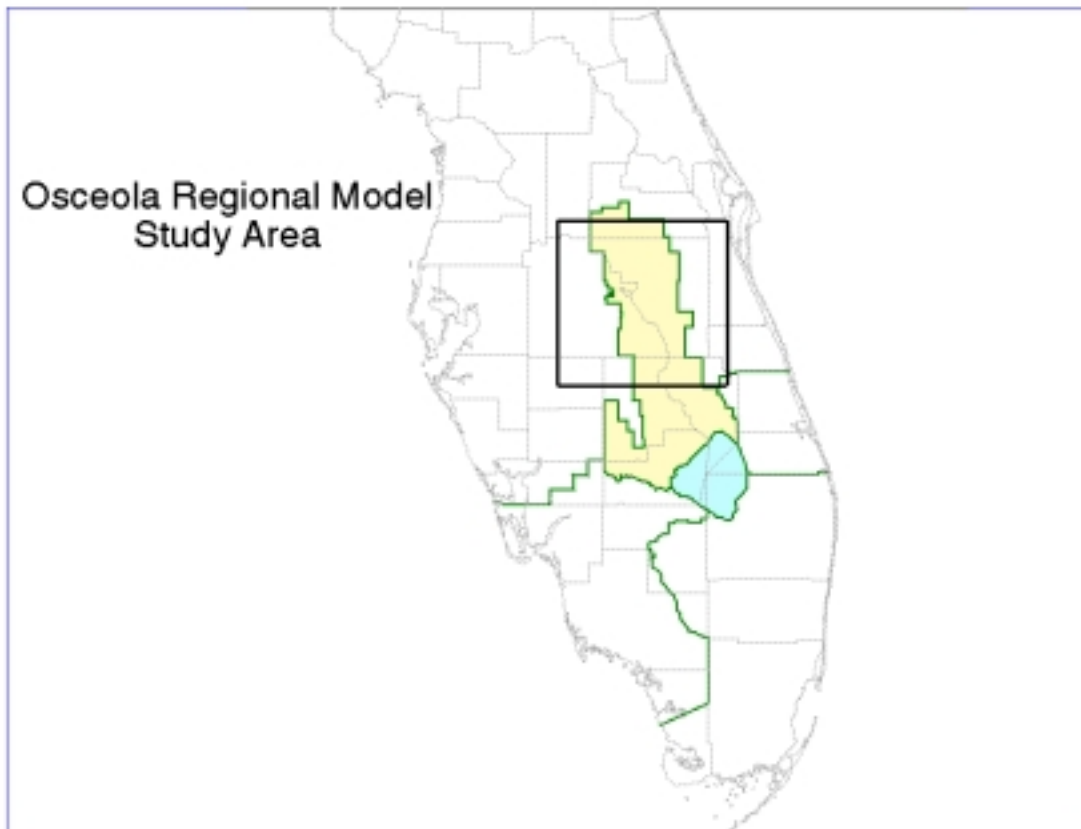
- LFA - Oldsmar Formation
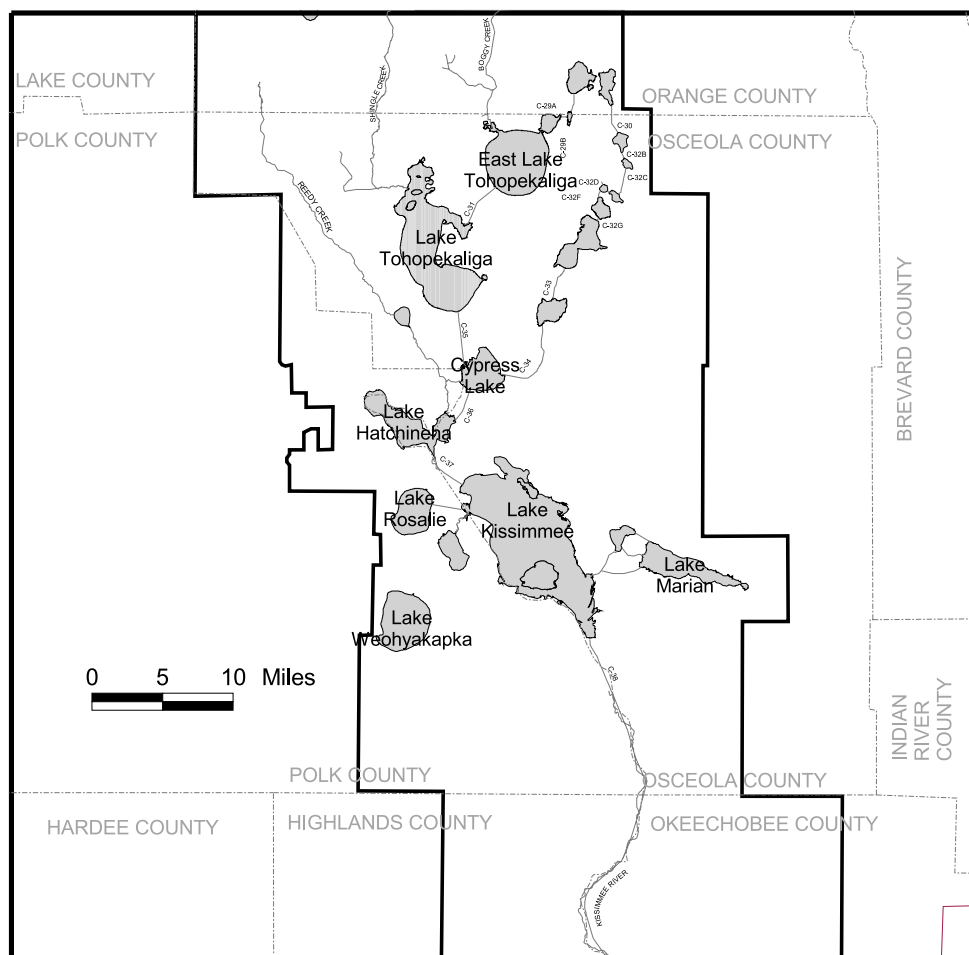
Figure H-1.   Location Map of Study Area.

Figure H-2.   Map of Study Area.

Depth (feet)

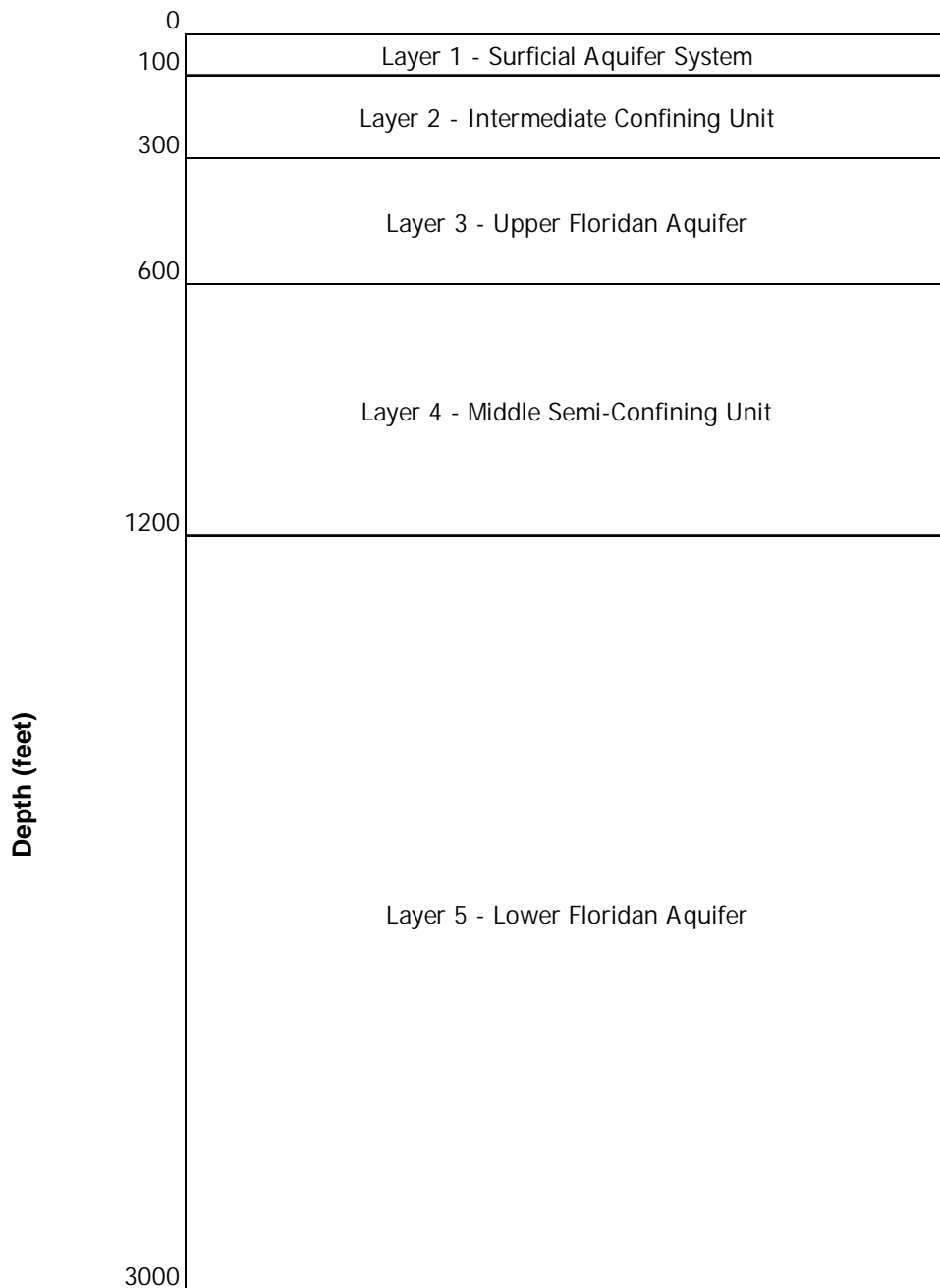| Depth	Layer
0	
100	Layer 1 - Surficial Aquifer System
	Layer 2 - Intermediate Confining Unit
300	
	Layer 3 - Upper Floridan Aquifer
600	
	Layer 4 - Middle Semi-Confining Unit
1200	
	Layer 5 - Lower Floridan Aquifer
3000	

Figure H-3.   Vertical Discretization of Osceola Regional Model.

Since the UFA is the most widely used aquifer in the study area, the majority of the reconnaissance work focused on this aquifer. District staff developed 6 test sites in Osceola County. These sites were used to obtain geologic and hydrologic data.

Model Development

Overview

The code used in this study to simulate the ground water flow is the U.S. Geological Survey (USGS) modular three-dimensional finite-difference ground water flow code MODFLOW (McDonald and Harbaugh, 1988). Most of the information for model development, calibration, and sensitivity analysis was derived from Butler (1999). Readers desiring more detail on the Osceola model are referred to this publication. Since the model is still in draft form, some change may occur between this report and the final documentation.

Horizontal and Vertical Discretization

The horizontal model grid consists of 134 rows and 137 columns. The grid spacing is a uniform 2,640 feet throughout the model area. **Figure H-4** displays the model grid.

Vertically, the model was discretized into 5 separate hydrologic units: the SAS, ICU, UFA, MCU, and the LFA. This study focuses on the Upper Floridan. Figure 3 depicts the model layers with their corresponding hydrogeologic units.

Hydraulic Characteristics

An initial value of 15 ft/d will be used for the hydraulic conductivity of the SAS. An initial estimate of 0.15 ft/d was estimated for the vertical conductivity.

Layer one is modeled as an unconfined layer and assigned a specific yield of 0.2. This value is within the range for specific yield measurements of unconfined sediments as indicated by Fetter (1980, p. 68).

The ICU separates the SAS from the FAS.

MODFLOW uses the Vcont parameter to estimate vertical flows between layers. According to McDonald and Harbaugh (1988), when the is a great discrepancy between the vertical conductivity of two adjacent layers, the Vcont may be estimated by the following formula:

Vcont(i,j,k) = 2 vc(i,j,k / thick(i,j,k) (1)

where

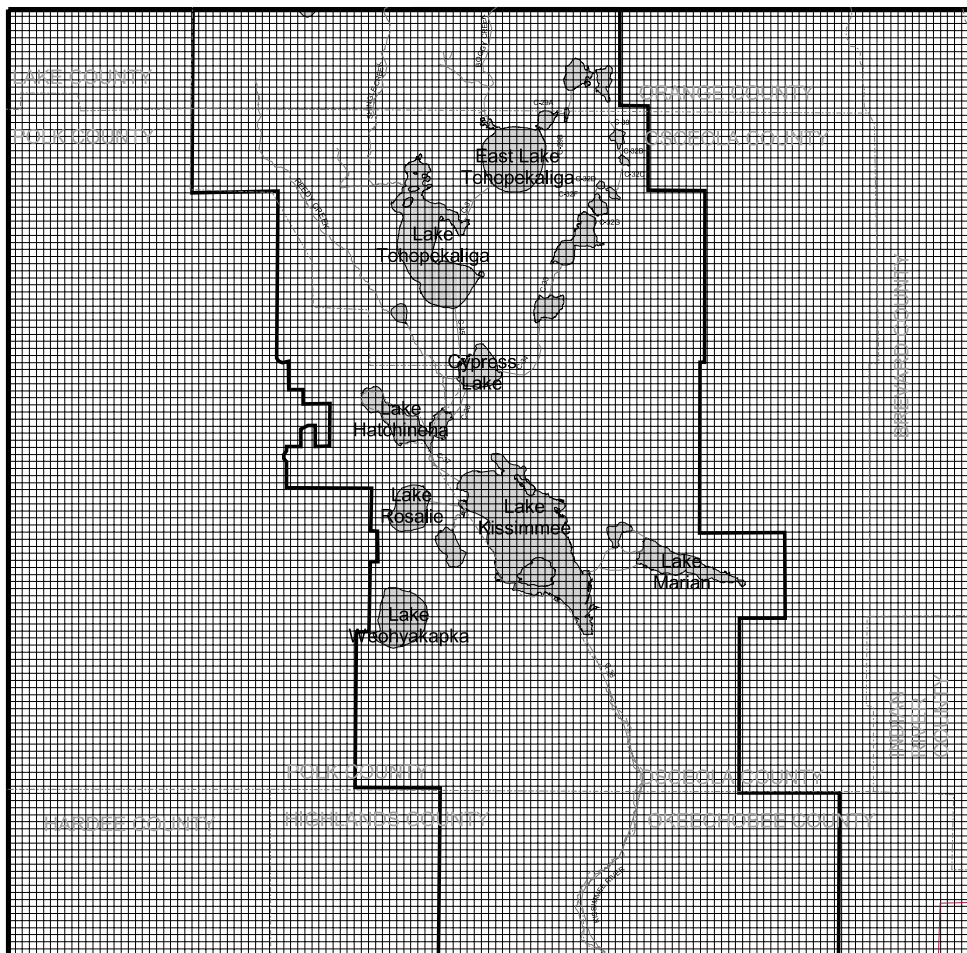*vc(i,j,k) = the vertical conductivity of the lower permeability layer*

Figure H-4.   Model Grid.

and

thick(i,j,k) = the thickness of the lower permeability layer.

This situation exists between layers 1 and 2, and between layers 2 and 3. Using the available hydrogeologic data, a vertical conductivity of 0.0135 ft/d was derived.

There are areas in the study area where the Hawthorn is fairly thin. In these areas the Hawthorn may not act as a confining unit. Therefore, layer 2 was modeled as a confined/unconfined layer where the transmissivity may vary.

Several aquifer performance tests and specific capacity tests were conducted in the study area. The results from these tests used to derive the hydraulic conductivity for the UFA. Initially, the vertical conductivity for the UFA will be 1/100 of the hydraulic conductivity.

The MCU is modeled as a confined layer in this study. An initial value of 0.21 ft/d was used for the vertical conductivity and 6,500 ft^2/d was used for the transmissivity. This corresponds to a hydraulic conductivity of 13 ft/d with an average thickness of 500 ft.

Tibbals (1990) utilized a value transmissivity of 60,000 ft^2/d for most of the study area. The LFA was modeled as a confined layer.
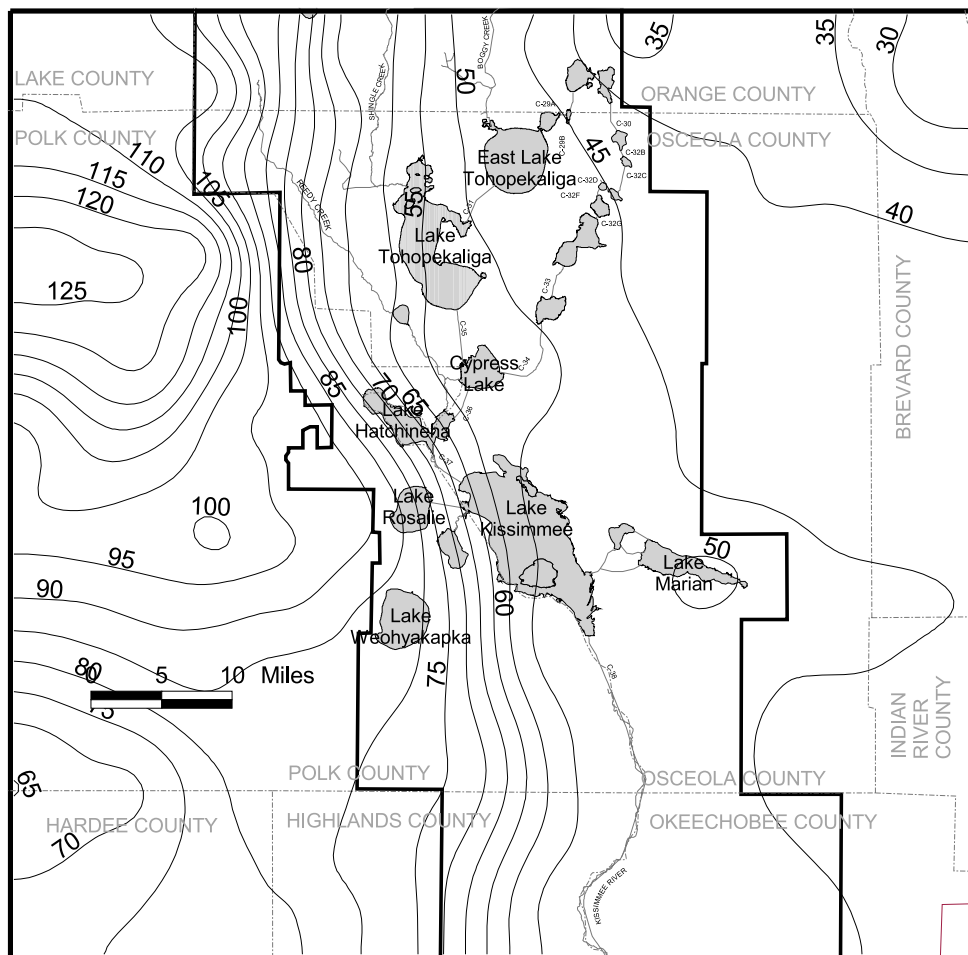
Water Levels

The SFWMD, in cooperation with the USGS and SJRWMD established water level monitoring network for the UFA in the study area. The study period was may 1992 through September 1995. **Figure H-5** is an averaged water level map of the UFA for the study area.

The District also established a map of the SAS. Since data for the SAS is sparse, surface water data from lakes, canals, and other surface water bodies sere used to supplement the data.

Very few monitoring wells penetrate the LFA within the study area. At the Bull Creek site, the SJRWMD has monitored a dual zone UFA/LFA monitor well for an extensive period of time. Results from the data indicate that the water level for the LFA ranges between 0.4 to 2.54 feet below the UFA. A uniform difference of 0.25 feet provided good model results.

Very few wells were finished within layers 2 or 4. For layer 2, the water level was set to the average value between the SAS and UFA. The water level for layer 4 was set equal to layer 5.

Contour Interval = 5 feet

Figure H-5.   Water Level Map of UFA.

Boundary Conditions

Many factors affect the water levels in layer 1. Some of the major factors are ground water withdrawals, rainfall, evapotranspiration, and the stages for the surface water bodies. It is not the intent of this study to simulate all of the effects. Therefore, layer 1 was modeled as a constant head boundary using the averaged water levels.

Since the UFA water level map, **Figure H-5**, has the most extensive network, it was used to establish the boundary conditions for layers 2, 3, 4, and 5. **Figure H-6** illustrates the boundary conditions for layers 2, 3, 4, and 5. The following discussion details how the boundaries were developed.

A review of **Figure H-5** reveals a potentiometric high in the western portion of the study area. The potentiometric mound acts as a ground water divide. Therefore, the apex of the mound is modeled as a constant head boundary. The cells west of the apex are modeled as no-flow boundaries.

A review of **Figure H-5** shows that the northern boundary intersects the equipotential line at approximately right angles. This implies that very little flow enters or leaves the study area from the north. Therefore, the northern boundary was modeled as a no-flow boundary.

The southern boundary was established approximately 10 miles south of the Osceola/Okeechobee border to minimize any potentially erroneous boundary effects. Similar to the northern boundary, the equipotential lines intersect the boundary at right angles; therefore it is modeled as a no-flow boundary.

A review of **Figure H-5**, indicates that ground water flows eastward in the study area. Furthermore, the figure reveals a relatively flat potentiometric surface in eastern Osceola and western Brevard counties. A constant head boundary was simulated near the eastern boundary of the study area.

Ground Water Use Estimates

As part of the 1995 calibration effort and again for future water use simulations, water use estimates were developed for entry into the constructed model. Development of the 1995 and 2020 water use database was completed in a series phases in order to capture the total water use picture. Water use was broken into areas of public water supply, permitted agriculture, non-permitted agriculture and water use outside the planning basin. The details on how each of these databases were developed is described in Appendix F, Water Use Estimates.

Water use from each of the developed databases were compiled to form the standard MODFLOW entry files. As estimated 6,000 wells were included with the model.
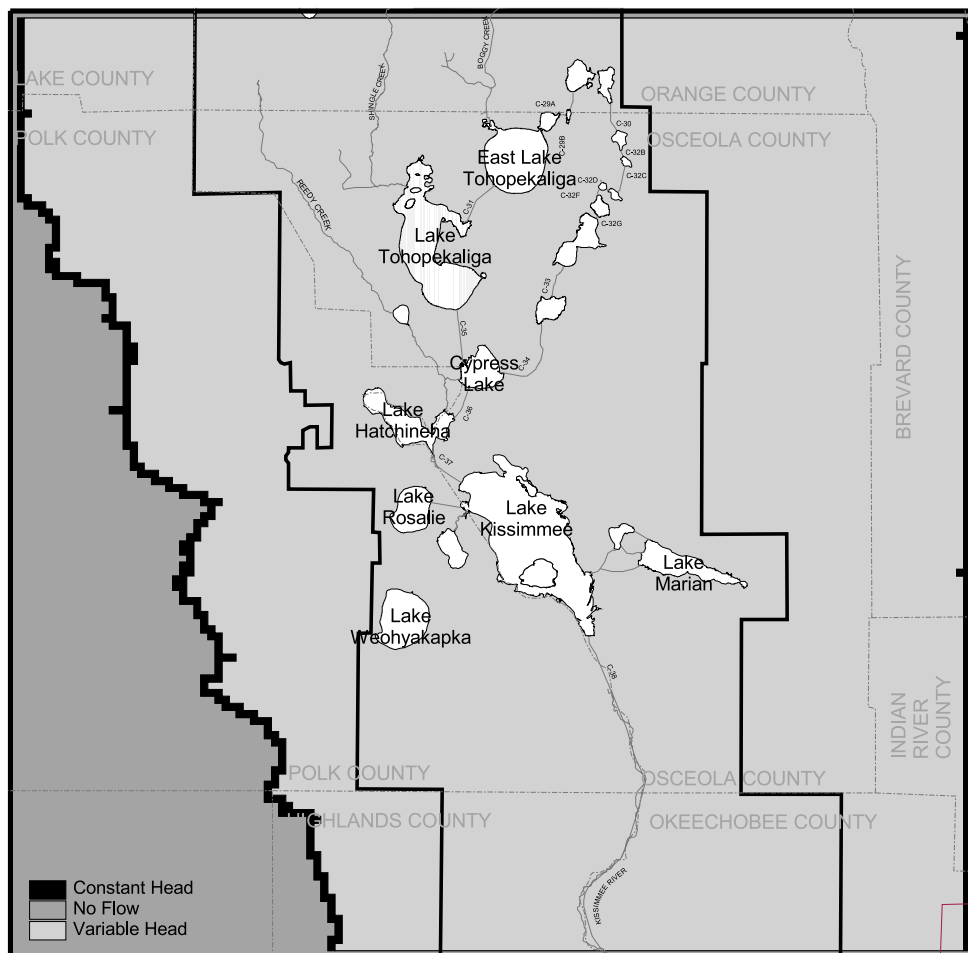
Figure H-6. Boundary Conditions.

Calibration

Introduction

Calibration is the process of adjusting the parameters of the numerical model so that the model responds similarly to the physical system. The Osceola County model was calibrated to steady-state conditions. Due to time constraints, a transient calibration was not performed.

"Steady-state" can be viewed as an average condition achieved over a long period of time. It presumes that no major changes in stress rates occur during that time. When the stresses that drive ground water flow change very slowly in time relative to the rate of change within the aquifer system, steady-state assumptions are justified. The basic statistics, including the standard deviation and variance, were estimated for each monitoring well. In most cases the standard deviation and variance are relatively small. This infers that there is little deviation from the mean water level. Based on the following it can be concluded that "quasi steady-state" conditions existed during the calibration period.

The basic procedure for calibrating the model is as follows. First, initial calibration criteria were developed for the model. Next, the model was initialized with reasonable parameters based on the results from hydrologic studies. Steady-state runs were used to make the adjustments to the model.

In order to measure the success of the calibration, the model results were compared to the actual water levels obtained from the monitoring well network. The monitoring network consisted of 53 wells that were distributed throughout the study area. Water levels from the wells were obtained on a monthly basis. Only layer 3 was calibrated using water levels.

In addition to examining the water levels, the calibration procedure also examines the vertical flow between the UFA and the SAS, and the model budget.

Water Level Calibration

The steady-state calibrations were based on comparison of simulated water levels under averaged conditions. Three criteria were used to measure the steady-state calibration:

1. The steady-state water level must be within one standard deviation of the averaged water level. At least 50% of the observation nodes must meet this criterion for the model to be considered calibrated.

2. The simulated steady-state water level for the observation node must be within the range of the maximum and minimum observed water levels for the corresponding well. At least 50%

of the observation nodes must meet this criterion for the model
to be considered calibrated.

3. The modeled water level for the observation node must be
within one foot of the averaged water level of the corresponding
well. At least 50% of the observation nodes must meet this cri-
terion for the model to be considered calibrated.

A more restrictive time period of October 1994 through September 1995 was used
for Criterion 3. This time period coincides with the base conditions used for the
Kissimmee Basin (KB) Water Supply Plan. There are some wells where the data for this
restrictive period are missing. In these cases, the average value for the entire study period
was used.

Table H-1 presents the results of the steady-state simulation. According to **Table
H-1**, 35 observation nodes (66%) meet the first calibration criterion, 44 observation nodes
(83%) meet the second criterion and 27 observation nodes (51%) meet the third criterion.
Also 22 observation nodes (41%) met all 3 criteria. Only 9 observation nodes failed to
meet any of the criteria.

Test runs were made with the model using the entire calibration period for
Criterion # 3. The results were similar to above.

Figure H-7 is a map of the steady-state water levels. The steady-state water level
map exhibits the same general trends as the average water level map (**Figure H-5**).

Anderson and Woessner (1992) recommend that a quantitative analysis of the
distribution error be conducted as part of the calibration assessment. In addition, they
provided levels for the calibration assessment. For Level 1, the simulated values fall
within the calibration target. For this study, if the simulated steady-state water level is
within ± 1-foot of the average value, it is defined as meeting the Level 1 calibration
criteria for steady-state conditions. Similar definitions apply for calibration levels 2, 3, and
4.

Figure H-8 is a residual map of the UFA. The residuals were determined by
subtracting the steady-state head from the mean observed water level. **Figure H-8** reflects
the absolute value from this difference. ARCINFO was used to help determine the areas
for levels 1, 2, and 4. Only the variable head cells were used in the computation. The
results are as follows:

- 69% of the study area meets level 1 criterion (steady-state water
levels are within 1.0 foot of the observed average value)

- 86% of the study area meets level 2 criterion (steady-state water
levels are within 2.0 feet of the observed average value)

- 91% of the study area meets level 3 criterion (steady-state water
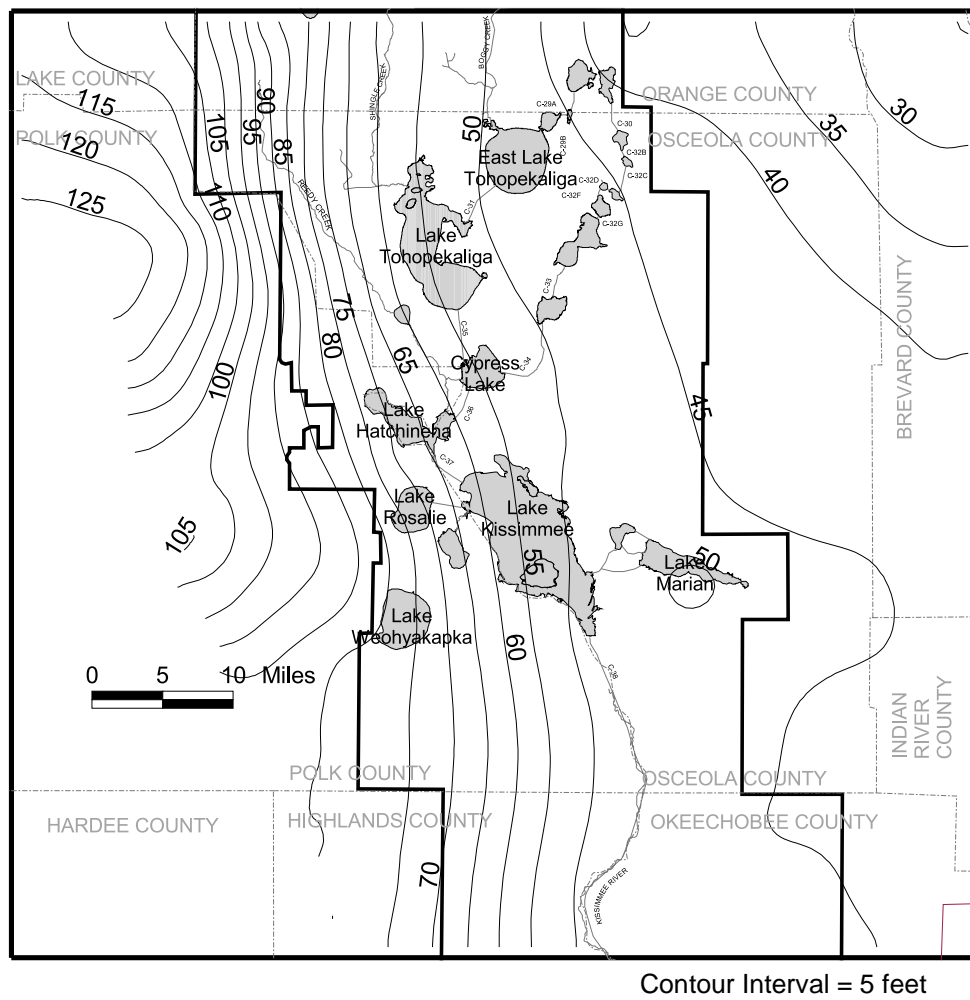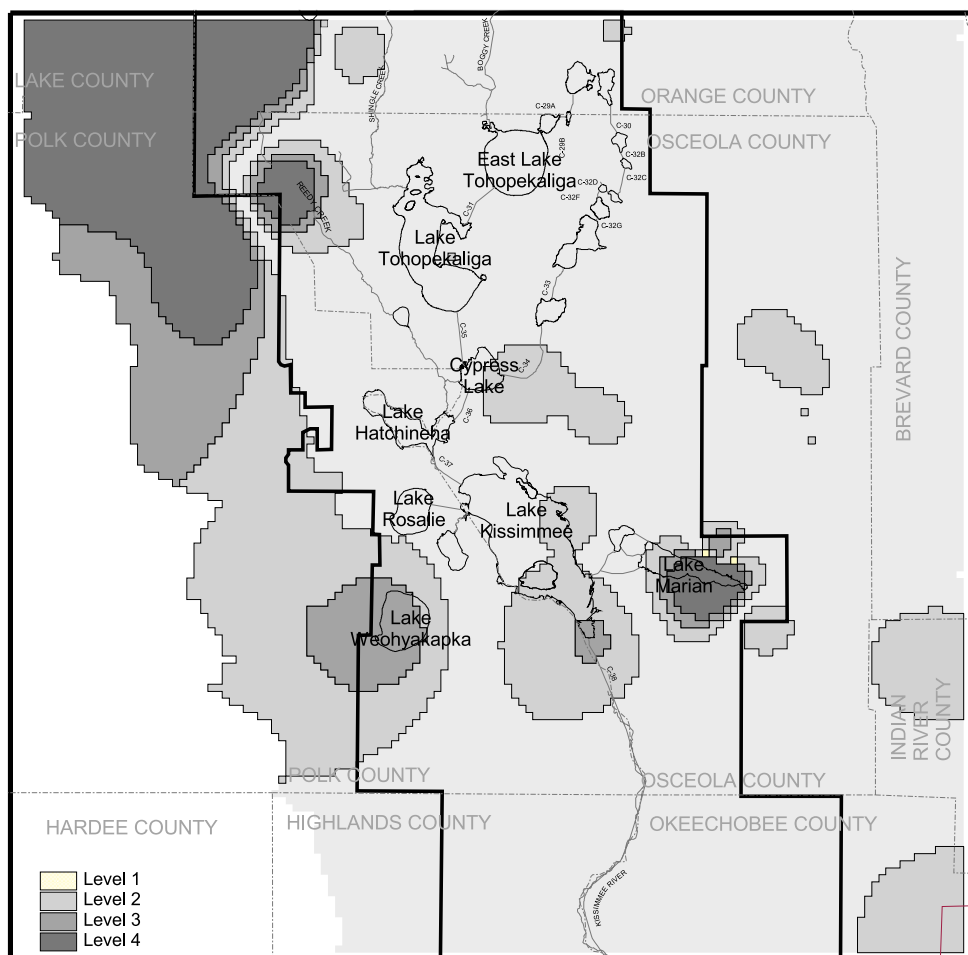levels are within 3.0 feet of the observed average value)

Contour Interval = 5 feet

Figure H-7.   Steady-State Water Level Map.

Figure H-8.   Residual Water Level Map.

Table H-1. Steady-State Calibration Results.

Layer	Row	Column	ID	SS Value	Mean	Minimum	Maximum	Results
3	100	110	1	45.21	44.89	42.61	46.76	Criteria 2 and 3
3	89	82	3	48.64	46.38	43.21	48.08	Uncalibrated
3	87	107	4	47.50	45.90	41.86	47.27	Uncalibrated
3	80	100	5	50.06	58.63	54.28	58.64	Uncalibrated
3	71	80	6	49.25	47.94	44.66	50.13	Criteria 2
3	65	99	8	45.01	44.62	41.60	46.38	Criteria 2 and 3
3	59	113	10	42.99	42.11	40.15	44.14	Criteria 1, 2 and 3
3	50	118	11	41.92	42.18	39.31	43.95	Criteria 1, 2 and 3
3	43	64	13	53.66	53.00	49.60	55.03	Criteria 1, 2 and 3
3	39	52	15	63.20	63.40	60.34	65.63	Criteria 1, 2 and 3
3	39	73	17	49.52	49.17	46.76	51.20	Criteria 1, 2 and 3
3	35	63	21	52.73	51.72	49.07	53.82	Criteria 1 and 2
3	29	48	23	65.71	64.34	62.33	66.27	Criteria 2
3	28	78	24	46.78	46.68	44.13	48.95	Criteria 1, 2 and 3
3	28	72	25	47.89	47.50	43.27	49.84	Criteria 1, 2 and 3
3	26	40	26	79.94	75.15	73.08	76.54	Uncalibrated
3	25	54	27	58.43	59.06	56.60	62.33	Criteria 1, 2 and 3
3	24	108	28	39.58	40.04	36.77	41.87	Criteria 1, 2 and 3
3	24	101	29	41.68	42.01	39.10	43.91	Criteria 1, 2 and 3
3	22	87	31	44.38	45.20	41.72	47.20	Criteria 1, 2 and 3
3	22	79	32	46.16	45.80	40.18	48.47	Criteria 1, 2 and 3
3	14	79	37	44.91	45.25	42.89	47.31	Criteria 1, 2 and 3
3	43	100	38	43.26	42.75	40.33	44.65	Criteria 2 and 3
3	104	119	40	43.08	42.11	39.30	43.68	Criteria 2 and 3
3	76	101	41	48.36	45.40	41.98	47.11	Uncalibrated
3	52	73	42	51.61	53.54	49.23	55.31	Criteria 1 and 2
3	58	84	43	48.45	49.66	45.50	52.80	Criteria 1 and 2
3	38	90	44	45.15	44.15	39.88	46.21	Criteria 2 and 3
3	27	67	45	49.88	50.04	46.51	52.74	Criteria 1, 2 and 3
3	51	113	46	42.62	43.96	39.97	45.94	Criteria 1 and 2
3	51	115	47	42.42	43.88	39.79	45.50	Criteria 1 and 2
3	57	113	48	42.91	44.01	39.86	45.88	Criteria 1 and 2
3	61	114	49	42.97	44.07	39.98	46.10	Criteria 1 and 2
3	46	106	50	42.79	44.21	39.00	45.47	Criteria 1 and 2
3	109	90	51	46.82	46.99	43.46	48.56	Criteria 1, 2 and 3
3	11	28	52	103.94	109.42	107.80	110.46	Uncalibrated
3	8	99	53	37.28	37.69	34.04	39.55	Criteria 1, 2 and 3
3	6	49	54	63.50	61.92	55.54	65.23	Criteria 1 and 2

Table H-1. (Continued) Steady-State Calibration Results.

Layer	Row	Column	ID	SS Value	Mean	Minimum	Maximum	Results
3	4	95	55	36.21	37.15	32.77	39.47	Criteria 1, 2 and 3
3	3	37	56	78.54	87.24	81.95	89.83	Uncalibrated
3	3	87	57	34.29	35.60	30.17	38.71	Criteria 1 and 2
3	3	91	58	34.84	34.75	29.85	37.63	Criteria 1, 2 and 3
3	3	90	59	34.46	34.53	28.99	38.49	Criteria 1, 2 and 3
3	14	69	61	49.27	50.06	44.45	52.59	Criteria 1, 2 and 3
3	89	80	63	49.69	47.85	44.90	49.12	Uncalibrated
3	88	53	64	79.73	82.20	77.25	84.56	Criteria 2
3	49	19	66	120.43	122.94	116.75	125.31	Criteria 1 and 2
3	38	17	67	126.65	128.83	124.63	130.12	Criteria 2
3	34	27	68	117.81	126.60	123.11	128.01	Uncalibrated
3	73	125	69	43.03	43.66	40.08	44.78	Criteria 1, 2 and 3
3	10	133	70	27.03	27.27	25.54	29.08	Criteria 1, 2 and 3
3	94	128	71	43.17	44.86	38.79	45.49	Criteria 1 and 2
3	128	131	81	44.33	45.73	42.09	47.17	Criteria 1 and 2

Number of nodes within one standard deviation= 35 or 66%.

Number of nodes within range = 44 or 83% percent.

Number of nodes where the difference is less than 1 ft = 27 or 51%.

Number of nodes meeting all criteria = 22 or 41%.

There are a few areas where the residuals exceed 3 feet. These areas seem to be associated with relatively high ground water gradients in either the SAS or the UFA.

Based on the given discussion, the model adequately simulates the water levels in the UFA.

UFA Recharge

Another calibration test is to see if the model simulates the interaction between the SAS and the UFA. **Figure H-9** is a recharge map of the UFA. It depicts areas of recharge and discharge based on the model. This map was compared with the recharge map from Tibbals (1990) report. This comparison is qualitative in nature.

An examination of **Figure H-9** indicates that most of the study area is a recharge area for the UFA. However, there are 2 major discharge areas. One are of discharge is located near the Osceola/Polk County border. This area contains portions of Lake Kissimmee, the Kissimmee River, and several large lakes. The other major discharge area is located near the eastern boundary of the study area. A review of the SAS water level map indicates that the water levels are fairly low in this area. The recharge maps from Tibbals (1990) reveals similar patterns for the discharge areas.
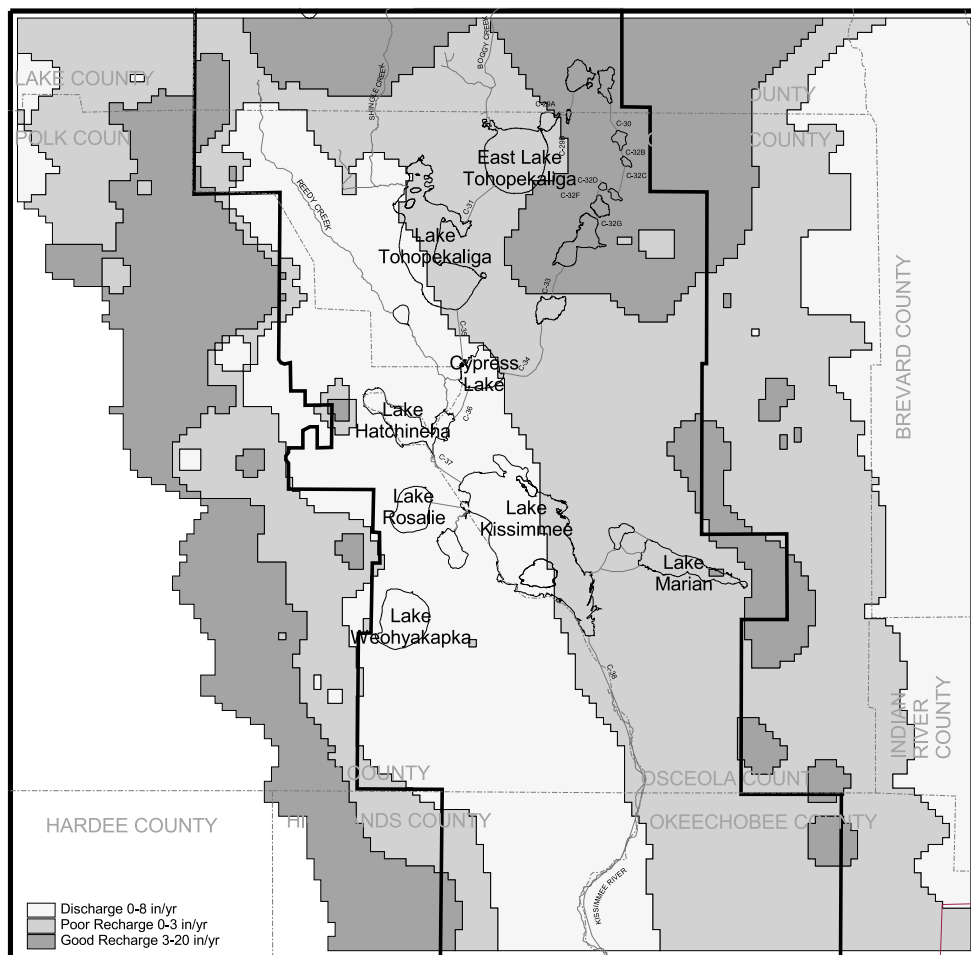
Figure H-9. Recharge Map.

According to **Figure H-9**, there is an area of high recharge located in the western portion of the study area. In this area both the SAS and UFA have fairly high water levels. However, the water levels in the SAS are higher. Also, the Hawthorn Group is fairly thin throughout most of this area. The recharge map by Tibbals has a similar pattern.

There are some differences between the two maps. **Figure H-9** depicts two other high recharge areas. On area is located in the north central portion of the study area. When compared to Tibbals (1990), the high recharge area in **Figure H-9** extends further south. Also, another high recharge area exists in the south central portion of the study are that does not have a have counter part on the recharge maps by Tibbals (1990). A review of the SAS and UFA water level in these areas indicates that the SAS is fairly high in these areas, which accounts for the extra recharge.

Overall, there is a good comparison between the recharge map by Tibbals (1990) and **Figure H-9**. Since different wells and observation points were used to make the two maps, the maps will not be exactly alike. However, a review of the SAS and UFA water level maps in conjunction with the isopach map for the Hawthorn, helps to justify **Figure H-9**.

Based on the given discussion, it can be concluded that the model adequately simulates the flows between the SAS and the UFA. It can be concluded that the estimated SAS water levels and the Vcont for the Hawthorn Group are reasonable.

Volumetric Budget

Table H-2 and **Figure H-10** present the results of the budget analysis. According to Table 2, $5.44*10^7$ ft^3/d enters the model and leaves the model area. The volumetric error is 0.53%.

Table H-2. Steady-State Withdrawal Rates.

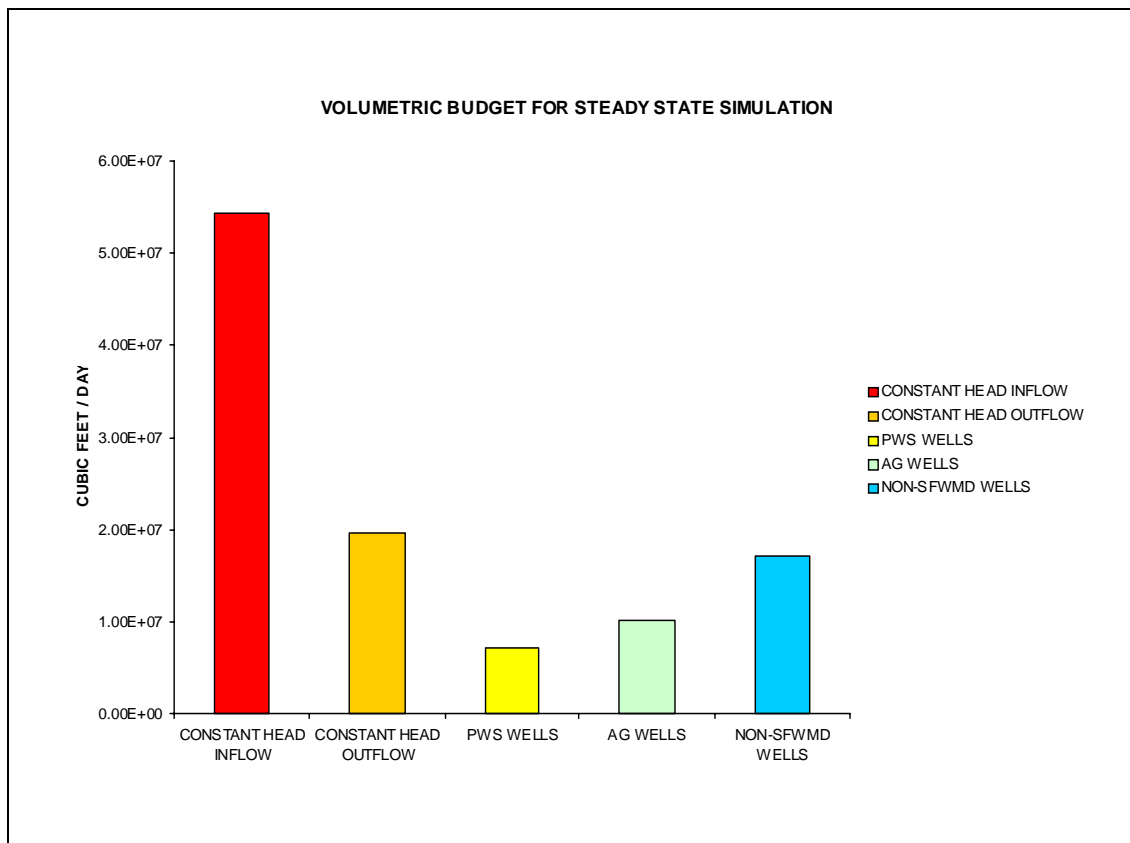| Parameter	Flow Rate (million ft^3/day)
Constant Head (input)	54.441
Constant Head (output)	19.611
PWS Withdrawal (output)	7.262
Agricultural Withdrawals (output)	10.124
Non-SFWMD Withdrawals (output)	17.130
Input – Output	0.288

Percent Discrepancy = 0.53%

Figure H-10. Volumetric Budget for Steady-State Simulation.

Sensitivity Analysis

A preliminary sensitivity analysis was done for the KB Water Supply Plan. **Table H-3** presents the results from the analysis. The head changes in Table 3 only apply to layer 3.

Table H-3. Results from Sensitivity Analysis.

Parameter	Maximum Change	Average Change	Minimum Change	Standard Deviation
Starting Heads for Layer 1 increased by 2 feet	0.44	0.11	0.00	0.06
Starting Heads for Layer 1 decreased by 2 feet	0.00	-0.11	-0.44	0.06
Starting Heads for Layer 3 increased by 2 feet	2.01	1.06	0.34	0.38
Starting Heads for Layer 3 decreased by 2 feet	-0.22	-1.07	-2.00	0.39
Starting Heads for Layer 5 increased by 2 feet	1.47	0.71	0.00	0.35
Starting Heads for Layer 5 decreased by 2 feet	0.00	-0.69	-1.40	0.34
Multiply VCONT(Layer 2) by 10.0	15.03	2.28	-8.98	4.89
Multiply VCONT(Layer 2) by 2.0	1.89	0.21	-1.04	0.50
Multiply VCONT(Layer 2) by 0.5	0.61	-0.13	-1.33	0.30
Multiply VCONT(Layer 2) by 0.1	1.19	-0.27	-3.02	0.62
Multiply VCONT(Layer 4) by 10.0	1.57	-0.05	-1.01	0.21
Multiply VCONT(Layer 4) by 2.0	0.45	-0.03	-0.43	0.09
Multiply VCONT(Layer 4) by 0.5	0.60	0.04	-0.38	0.10
Multiply VCONT(Layer 4) by 0.1	1.94	0.13	-1.01	0.32
Multiply Kh of UFA by 2.0	3.88	0.05	-0.61	0.29
Multiply Kh of UFA by 0.5	0.87	-0.06	-6.64	0.38
Multiply T of LFA by 5.0	0.46	-0.02	-0.33	0.05
Multiply T of LFA by 2.0	0.27	-0.01	-0.19	0.03
Multiply T of LFA by 0.5	0.28	0.01	-0.42	0.05
Multiply T of LFA by 0.2	0.74	0.03	-1.13	0.12
Multiply all pumpage by 1.30	0.00	-0.07	-2.66	0.13
Multiply all pumpage by 1.10	0.00	-0.02	-0.89	0.04
Multiply all pumpage by 0.90	0.88	0.02	0.00	0.04

The starting heads for layers 1, 3, and 5 were each changed by ±2 feet. According to Table 3, the model is most sensitive to changes in the starting heads for layer 3. It is the least sensitive to the starting heads for layer 1.

The sensitivity analysis for Vcont was examined by varying the vertical conductivity of layers 2 and 4. The model is more sensitive to the vertical conductivity of layer 2 that it is for layer 4.

Multiplying and dividing the hydraulic conductivity by a factor of 2 has some effect on the model. The average heads changes are small 0.05 feet and -0.06 feet respectively. However, the maximum and minimum changes for doubling the starting heads are 3.88 feet to -0.61 feet respectively; and the results of halving the hydraulic conductivity are 0.87 feet to -6.64 feet respectively.

According to **Table H-3**, doubling and halving the hydraulic conductivity for layer 3 affects the model more than doubling and halving the vertical conductivity for Layer 4.

Altering the transmissivity for layer 5 had little impact on the model.

Altering the pumpage by factors of 1.3, 1.1, and 0.9 had little impact on the model.

Conclusions and Recommendations

1. There is a good correlation between the averaged water level and the steady-state water levels. Also, the model acceptably simulates the flows between the SAS and the UFA.

2. District staff should finish the modeling process. This includes completing the QA/QC procedures and preparing the final documentation. Also, the reconnaissance work for the model should be documented.

3. From the preliminary sensitivity analysis, the model is most sensitive to changes in the starting heads of layer 3, the hydraulic conductivity of layer 3, and the vertical conductivity of layer 2. District staff should calculate the relative sensitivities for these parameters. Relative sensitivities allow comparison across parameters.

4. Future work in the Osceola area should include installing more observation wells in the LFA, testing the vertical conductivity of the MCU, and analyzing the relationship between the water levels of the UFA and LFA.

5. The model is more sensitive the vertical conductivity of Layer 2 than of layer 4. Future work in the study area should include testing the vertical conductivity of layer 2. District staff should also examine the relationship between the lakes in the study area and the water levels in the UFA.

6. Prior to developing a transient model for the Upper Floridan, the District should develop a model of the SAS.

7. District staff should calculate the relative sensitivities for the parameters used in the sensitivity analysis. This will allow comparison across parameters.

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II. GLADES, OKEECHOBEE, AND HIGHLANDS (GOH) MODEL

Purpose and Scope

The purpose of the Glades, Okeechobee, Highlands (GOH) model development was to develop a calibrated steady-state three-dimensional ground-water flow model to simulate the UFA underlying the southern Kissimmee River Basin. The model developed was used to evaluate the effects of projected increases in ground water withdrawals from the UFA. Pumpage estimates from 1995, and projected pumpage estimates from 2020 were used to evaluate the effects of projected increases in pumpage. These effects are defined in terms of simulated steady-state drawdown of UFA water levels relative to 1995 conditions.

The model was developed to provide support for the development of a regional comprehensive water supply plan for the Kissimmee Basin by the SFWMD Water Supply and Planning Department.

Location of Model Area

The area encompassed by this model is located in the southern Kissimmee River Basin and surrounding areas and is shown in **Figure H-11**. Portions of Glades, Okeechobee, and Highlands counties comprise the GOH model area. For this reason, the model is commonly referred to as the GOH model. The exterior areas of the GOH model also include small portions of the following counties: Polk, Osceola, Indian River, St. Lucie, Martin, Palm Beach, Charlotte, Desoto, and Hardee counties. The extension of the model into these surrounding counties allows for more accurate modeling of conditions within the "core" of the model. Typically, with any model, the best model results are obtained away from the periphery of the model where boundary conditions tend to limit a model's flexibility to accurately mimic the natural system.

Early in the model development process, during the data collection phase, the model focused on Okeechobee County. The data coverage within Okeechobee County is consequently better than in the other areas in the model.

Aquifers in the areas immediately surrounding the GOH model have previously been modeled by several different agencies. The models reviewed to aid in the conceptualization and development of the GOH model were: Butler and Padgett (1995), Lukasiewicz (1992), Planert and Aucott (1985), Murray and Halford (1999), and Yobbi (1994). In addition, a Floridan Aquifer model for Osceola, southern Orange and eastern Polk counties was being developed concurrently with the GOH model (Butler, 2000). To insure continuity of several model parameters including conceptualization, lithologic interpretation, and water level information, SFWMD staff coordinated modeling efforts.
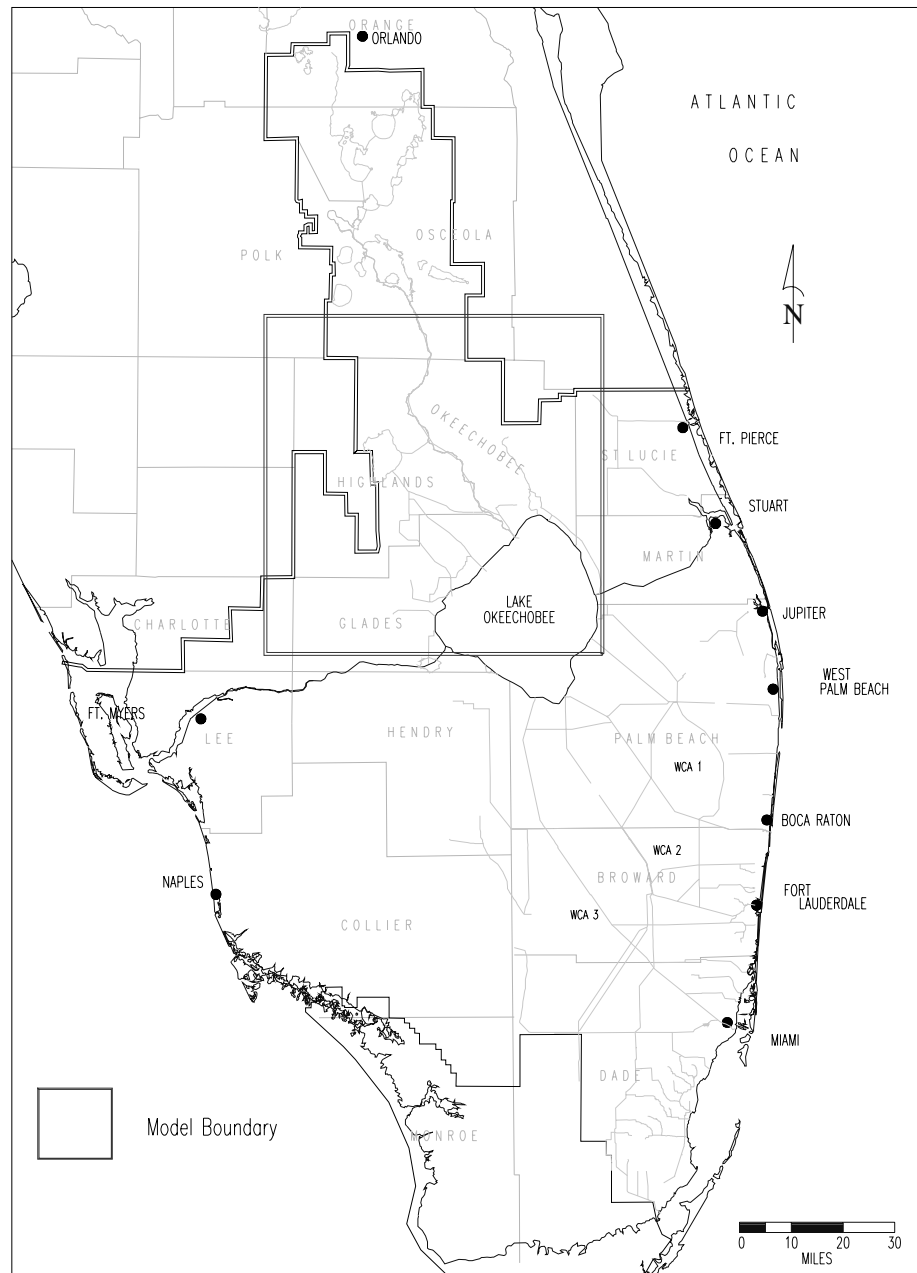
Figure H-11. Map of Study Area.

Data Collection

The area encompassed by the GOH model is one of the least populated areas of the SFWMD, with most of the population concentrated along the Lake Wales Ridge and on the northern shore of Lake Okeechobee. In addition, the agricultural development within the basin is, in general, less intensive than other areas of the SFWMD. The majority of work conducted in the area by the SFWMD has focused on surface water runoff/nutrient loading especially with regards to Lake Okeechobee; therefore, there is less historic ground water data available in the study area. In addition, available water resources have been adequate to supply existing water supply needs. Because this has not been an area of water shortage concern, there have been less historic studies focusing on the area, and consequently less data is available. Several publications proved valuable in providing lithologic and hydrogeologic data necessary for model development (Shaw and Trost, 1984a; Shaw and Trost, 1984b; CH2M Hill, 1989; Bradner, 1992; and Schiner, 1993).

Despite the publications listed above, available ground water and lithologic data was sparse in the model area. Because of this dearth, the SFWMD collected necessary data between 1994-1997 to develop a more representative GOH model. This included the construction of ten FAS wells at four sites and 52 SAS wells at 15 sites. Multiple wells were installed at most sites to monitor distinct zones, and to collect data for aquifer performance tests. The results of these efforts are unpublished to date.

Hydrogeology of the Model Area

Two major aquifer systems underlie the study area; the SAS and the FAS. Both aquifer systems are continuous throughout the study area and contain discreet production zones and/or aquifers. For the GOH model development, the SAS was depicted as one model layer, while the FAS was split into two distinct production zones separated by the MCU. **Figure H-12** depicts the generalized layering that was used for the model development

The SAS (model layer 1) yields potable water throughout the majority of the study area and is commonly used as a source of private drinking water supply. However, the transmissivity of the SAS is relatively low throughout most of the study area, and when large quantities of water are required for irrigation, commercial supply, or public water supply, the FAS is the water supply source that is most frequently utilized. Three distinct production zones are present within the SAS in the study area, these range from unconfined to semi-confined and confined.

Underlying the SAS is the upper confining unit (model layer 2) composed of a thick sequence of silty-sandy clays comprising the Hawthorn Group and overlying Plio-Pleistocene silty-clays. This unit is an aquitard that limits the interaction of water between the SAS and the FAS. Because silty-clays at the base of the SAS are contiguous with the Hawthorn Group, they are considered to be part of this confining layer. The confining unit is not synonymous with the Hawthorn Group, however the Hawthorn Group, does constitute the bulk of the layer.
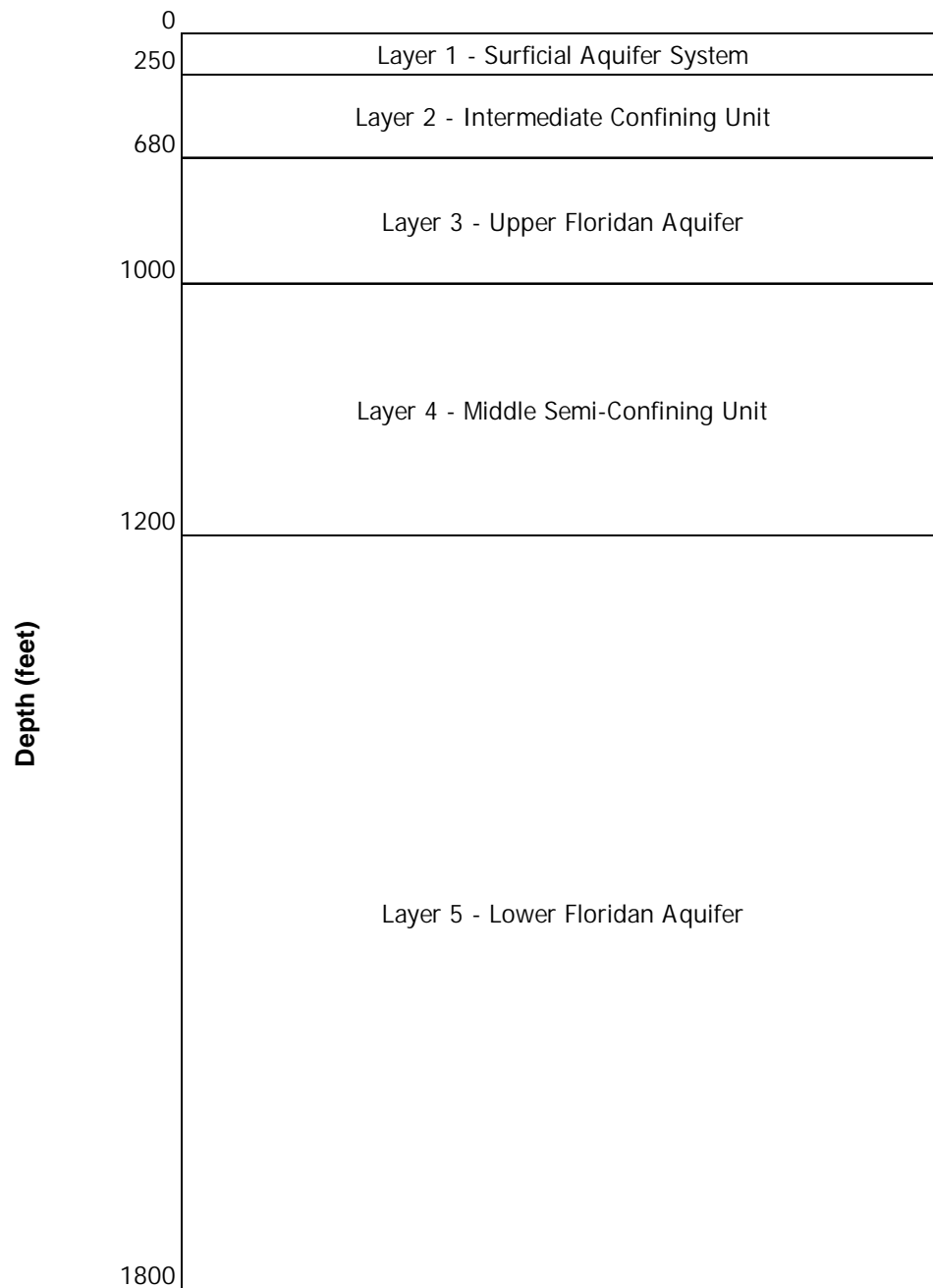
Figure H-12. Vertical Discretization of GOH Model.

Beneath the upper confining unit is the FAS. Previous models (Lukasiewicz, 1992; Planert and Aucott, 1985; Murray and Halford, 1999) developed for Central and South Florida have divided the FAS into three distinct layers, this is the approach used for the GOH model. These layers are, from top to bottom, UFA (model layer 3), MCU (model layer 4), and LFA (model layer 5).

The UFA in the model area is composed of the Ocala Group and upper, more-permeable portion of the Avon Park Formation. The decision as to how much of the Avon Park Formation was incorporated into Layer 3 was determined based on lithologic and geophysical data available from individual wells.

The UFA underlies the entire study area, and yields water that is acceptable for most uses in most areas. The presence of acceptable water quality and relatively high yields from wells has combined to make the UFA the primary source of ground water withdrawal within the study area. Water quality within the UFA degrades to the south and east. Water quality within the UFA also often degrades (primarily with increasing levels of chlorides and total dissolved solids) with depth; this is especially true to the south and east.

Immediately below the UFA is the MCU, which is a portion of the FAS with lower horizontal and vertical permeability. This unit is composed of the lower, less-permeable portion of the Avon Park Formation and acts as a semi-confining unit that separates the UFA from the LFA. Because of the depth, and the lower permeability in the MCU, few wells are drilled into or through this unit. This has limited the amount of data available to accurately assess and map the position and thickness of this layer. Based on a review of the wells with adequate data, it was decided that a uniform thickness of 200 feet would be applied across the model area. This uniform thickness was added to the base of the UFA (Layer 3). The limited number of wells penetrating the MCU and the difficulty of performing field tests to evaluate the degree of confinement, limits the amount of field data available to evaluate the degree of confinement.

The LFA (Layer 5) underlies the MCU, and is present beneath the entire the study area, however, it is not used significantly in most areas for two reasons: high cost of wells, and poor water quality.   The LFA is the deepest freshwater aquifer in the study area, therefore it is more expensive to complete wells into this aquifer. In addition, the presence of cavities (both open and sand filled) complicates the drilling process and can greatly increase drilling costs.

The water quality of the LFA varies significantly throughout the study area. In general, the water quality of the LFA underlying the Lake Wales Ridge and the extreme northern portion of the study area (southern Osceola and Polk counties) is acceptable for most uses. The water quality decreases to the south and to the east in the study area to the point where it is unacceptable for most uses away from the aforementioned areas.   Water quality within the LFA also generally degrades with depth in this study area. Heavy pumpage from the LFA can cause upconing of lower quality water from deeper zones within the aquifer; this is especially true to the south and east in the study area.

Both the UFA and LFA in this study area are karstic limestone aquifers whose principal productivity is from secondary permeability. This secondary permeability originates from the solutioning of limestone by water flowing through the aquifer over long periods of time. Recharge water typically follows the past of least resistance, which is generally along bedding planes, formation contacts, and fractures/faults in the rock matrix. Over geologic time, these features are enlarged enough so that large diameter conduits exist. These conduits can act similarly to a pipe network and move large volumes of water over long distances very quickly. This type of flow, often referred to as conduit flow, complicates data collection and interpretation.

If a well is drilled into the FAS (either Upper or Lower) and intersects a conduit, the well will likely be highly productive. A nearby well drilled into the exact same formation, that misses these cavities may have a productivity that is more than an order of magnitude lower. The local variability makes it difficult to predict results at a small scale (e.g. at a specific well), however, at a larger scale (e.g. a regional model), the local variability averages out and FAS models have proved accurate in the past at estimating aquifer impacts on a regional basis.

The thickness of the Hawthorn Group and Floridan aquifer sediments are generally thinnest to the north, along the northern boundary of the study area, and increase in thickness to the south. The SAS is thickest along the east central edge of the model, where there is a deeper production zone that increases the thickness of the aquifer. The SAS also thickens beneath the Lake Wales Ridge due to thick sand deposits associated with the ridge.

Model Development

Overview

The code used in this study to simulate ground water flow is the U. S. Geological Survey modular three-dimensional finite-difference ground water flow code MODFLOW (McDonald and Harbaugh, 1988). The model development process was aided significantly through the use of Groundwater Vistas (Environmental Simulations Inc., 1996), a unique ground water modeling environment for Microsoft Windows that couples a model design system with comprehensive graphical analysis tools.

The information used to determine the aquifer/confining unit parameters varied throughout the model area. In Okeechobee County the majority of the information is unpublished data collected by the SFWMD in direct support of this model development process. Previously existing data was also incorporated. Between 1992 and 1995, the District installed ten upper FAS monitoring wells at four sites, and 52 SAS wells at 15 separate sites. These wells were used for aquifer performance tests to determine aquifer parameters and for ground water level measurements that were used for model input, and/ or calibration targets.

In Glades and Highlands counties, the predominant source of information for aquifer parameters was previously published data from the SFWMD, the USGS, or other Florida water management districts. Previously existing data were also used for Okeechobee County, but it was supplemented with more recent information collected for the model.

Water level data used for model calibration and for estimating constant heads and boundary conditions were from several sources. The majority of the data was collected specifically for the modeling effort, however data from both the SFWMD and the USGS were used to supplement the model specific data. Unfortunately, due to personnel and budgetary constraints, all wells were not monitored as frequently, or for as long as would have been preferred for the model development. Ideally, for the model development, it would have been preferred to have two years worth of data collected at a monthly interval for all of the wells. Many of the FAS wells had only wet and dry season water level measurements, while some of the SAS wells had less than a full year of data when the monitoring was stopped.

Horizontal and Vertical Discretization

The horizontal model grid consists of 130 rows by 130 columns. The grid cell size is 2,640 feet by 2,640 feet (one-half mile). The model covers an area of 4,225 square miles. The one-half mile spacing was chosen because it is fine enough to satisfactorily assess the model area without overtaxing the computers that were available at the time for the model runs. This spacing also corresponded to that used for the Osceola County model that was being developed concurrently. The availability of data for the various model parameters would also limit the usefulness of utilizing a finer model; there would be little gain in model accuracy by going to a smaller grid size. **Figure H-13** displays the model grid overlain over a base map of the area.

Vertically, the model was discretized into five distinct hydrologic units as shown in **Figure H-12**. These five units are: The SAS, the upper confining unit, the UFA, the MCU, and the LFA.

The top and bottom elevations of all layers were determined by reviewing all available lithologic and geophysical data, and selecting the elevation picks for each model layer at each well.   The layer elevations and the well locations were then input into the software package Surfer for Windows (a contouring and 3-D surface mapping software package). A grid file was then generated by Surfer that had the elevations at all grid points contoured based on the existing known information. This grid file was identical to the GOH model grid file in terms of X and Y coordinates, grid spacing, and units. This allowed for the formation top and bottom elevation information to be imported directly into the model by using Groundwater Vistas. **Figure H-14** shows the top elevation for layer 3, the FAS.

This approach worked well for the upper three layers, however, a shortage of available data from the deeper formations precluded its use for the base of the MCU, the top of the LFA, and the base of the LFA. For these lower two layers, uniform thickness
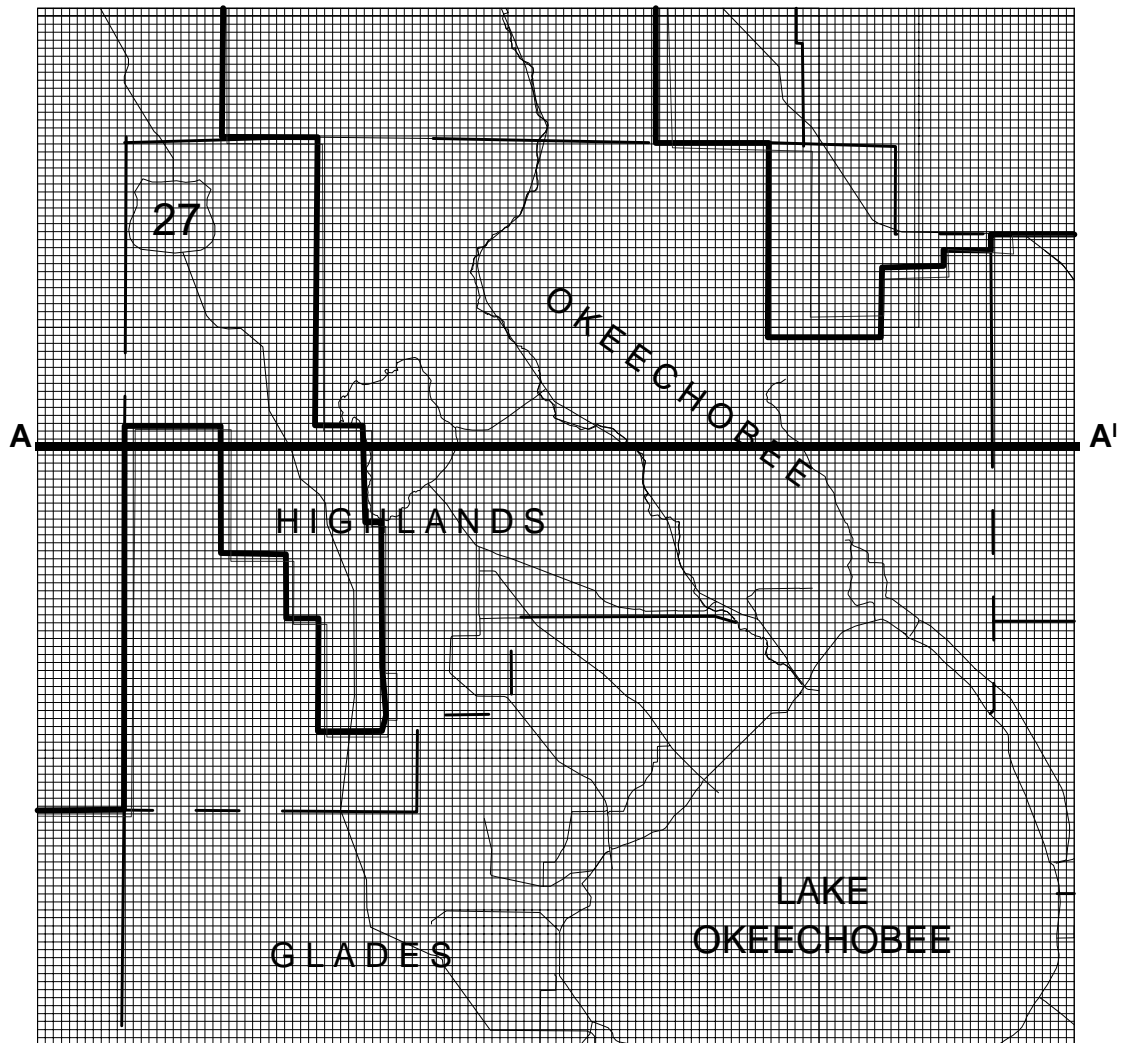
A to A¹ shows the location of the profile depicted in Figure H-17

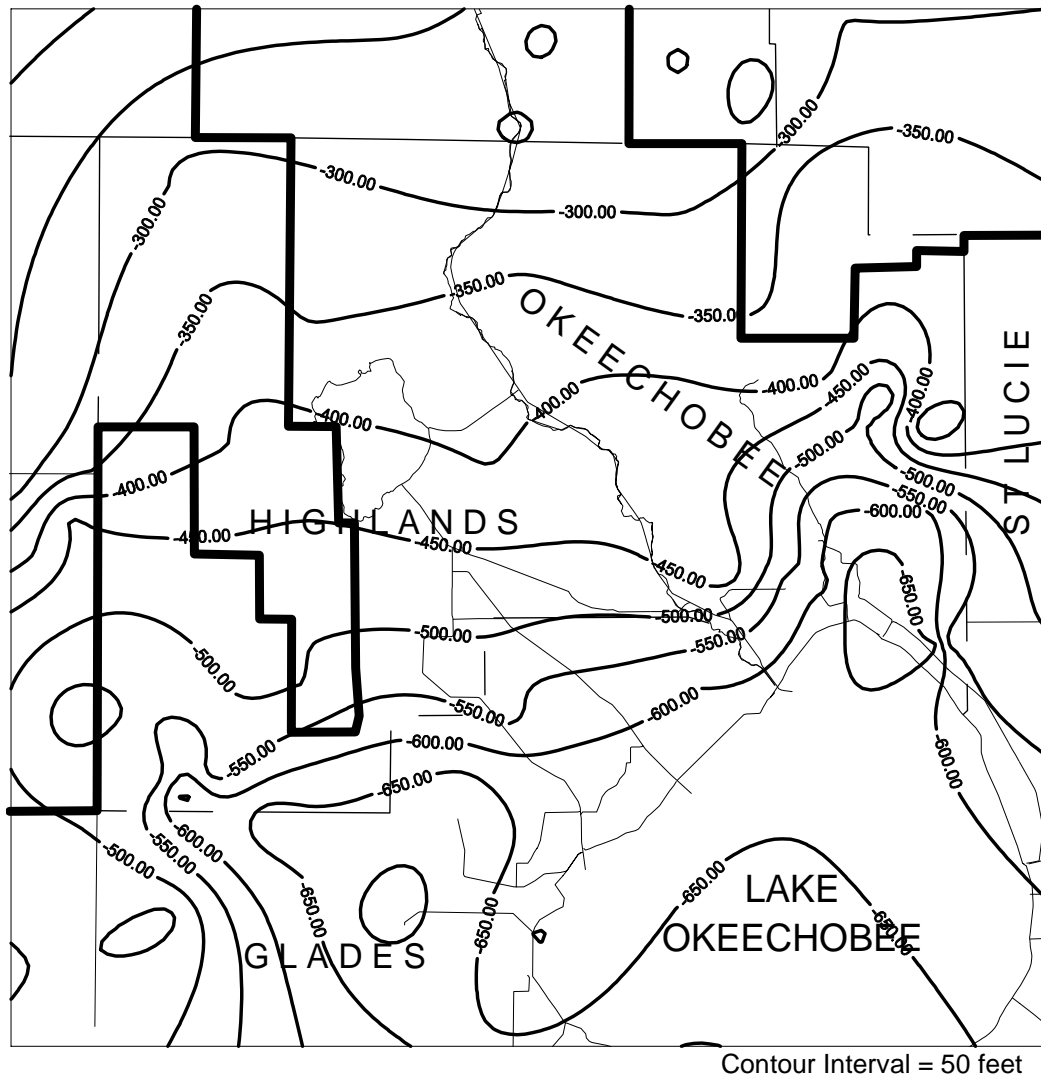**Figure H-13.** Model Grid.

Contour Interval = 50 feet

Figure H-14. Elevation of the Top of Layer Three (Top of Floridan Aquifer System).

values were assigned, a 200 ft. thickness for the MCU and a 400 ft. thickness for the LFA. These thickness values were added to the base of the UFA for these deepest layers. The 200 ft. thickness for the MCU was based on the available existing data, and the approach used by other models. The LFA is much thicker than 400 ft. However the since the LFA is being modeled as a constant head layer, the thickness of the zone does not affect the model.

The elevations of the layers that were modeled range from a high of 160 feet above Mean Sea Level (MSL) for the top of the Layer 1, to a low of 1,800 feet below MSL for the base of Layer 5.

Hydrologic Characteristics

SAS

The SAS was evaluated thoroughly during the data collection phase of the model development. There are three distinct producing horizons within the SAS that are present within various portions of the study area.

The original District plan was to model the SAS as an "active layer". However, that scope changed in response to a shift in District resources away from this model development.

The focus of this model is the UFA. The current and projected water use from the SAS in the study area did not justify the human resources necessary to thoroughly model the SAS. Instead, it was modeled as one layer with constant head values determined from measured water levels.

During the model development process it became apparent that it would be necessary to input accurate constant head water level elevations for the SAS in order to get calculated UFA water levels to calibrate to observed UFA water levels. This is especially true in the western portion of the model area near the Lake Wales Ridge where the SAS supplies recharge to the UFA. To do this, stage data from lakes, canals, and streams were used to supplement water level measurements from SAS monitoring wells.

Upper Confining Unit

The upper confining unit of the model (Layer 2, the Hawthorn Group and overlying plio-pleistocene clays) has a significant affect on calculated heads because it, to a large part, determines the interaction (recharge and discharge) between the UFA and the SAS. MODFLOW usually requires the model developer to input the vertical leakance or V_{CONT} term. However, Groundwater Vistas utilizes a different approach and calculates the vertical leakance from the vertical hydraulic conductivity and the layer thickness. This approach is better suited for the data available for the GOH model development as accurate formation thickness information exists, but leakance information is sparse and the accuracy is questionable. The estimates of horizontal and vertical conductivity for the

upper confining unit were derived from Fetter, 1980. A value of 0.01 ft/day was used for the vertical hydraulic conductivity of the upper confining unit. This value was selected because it is in the high range of values for clay (the Hawthorn Group in the model area is predominantly a clay with high sand and silt, the permeability is expected to be in the high range for clay).

UFA

Hydraulic conductivity values for the UFA were estimated by gathering all available transmissivity data (both published and unpublished). Hydraulic conductivity values (horizontal) were then calculated by dividing the transmissivity values by the aquifer thickness. The thickness of the aquifer values were determined from the lithologic and geophysical data collected at the aquifer performance test sites during monitoring well installation. The hydraulic conductivity data was, in turn, gridded and imported into Groundwater Vistas.

Vertical hydraulic conductivity was assumed to be one-tenth of the horizontal value. This is a common ratio of vertical to horizontal conductivity in sedimentary aquifers. Because grains and bedding plains orient themselves horizontally in a sedimentary aquifer, horizontal conductivity is generally ten times greater than vertical permeability. This relationship of horizontal to vertical permeability is also likely true where the majority of the permeability is due to secondary permeability for the solutioning of limestone. This solutioning generally occurs along previously established flow paths, such as along horizontal bedding planes and formation contacts. Horizontal hydraulic conductivity values ranged from a low of 2.5 ft/day to a high of 33 ft/day.

Boundary Conditions

As mentioned earlier, it was beyond the scope of this model project to develop a fully active Layer 1 (SAS). Instead, layer 1 was modeled as a constant head source, with the head values derived from the average of measured water levels. These water levels were measured from between October 1993 and September 1994 (a one year period with relatively average precipitation). Constant head values for layer 1 are displayed in **Figure H-15**.

No boundary conditions were used for Layer 2, the upper confining unit. This unit is a confining layer with low permeability. Because of this low permeability, it was assumed that the inflow and outflow along the periphery of the model would be negligible.

For Layer 3, the FAS, the predominant direction of water flow in the model area is west to east. Constant head cells were inserted along the easternmost and westernmost columns of the model. By inserting constant heads into these cells, the model can simulate lateral inflow and outflow. These constant head values were calculated by contouring the average water levels for the FAS, and then inserting the values corresponding with the easternmost and westernmost columns into the model.
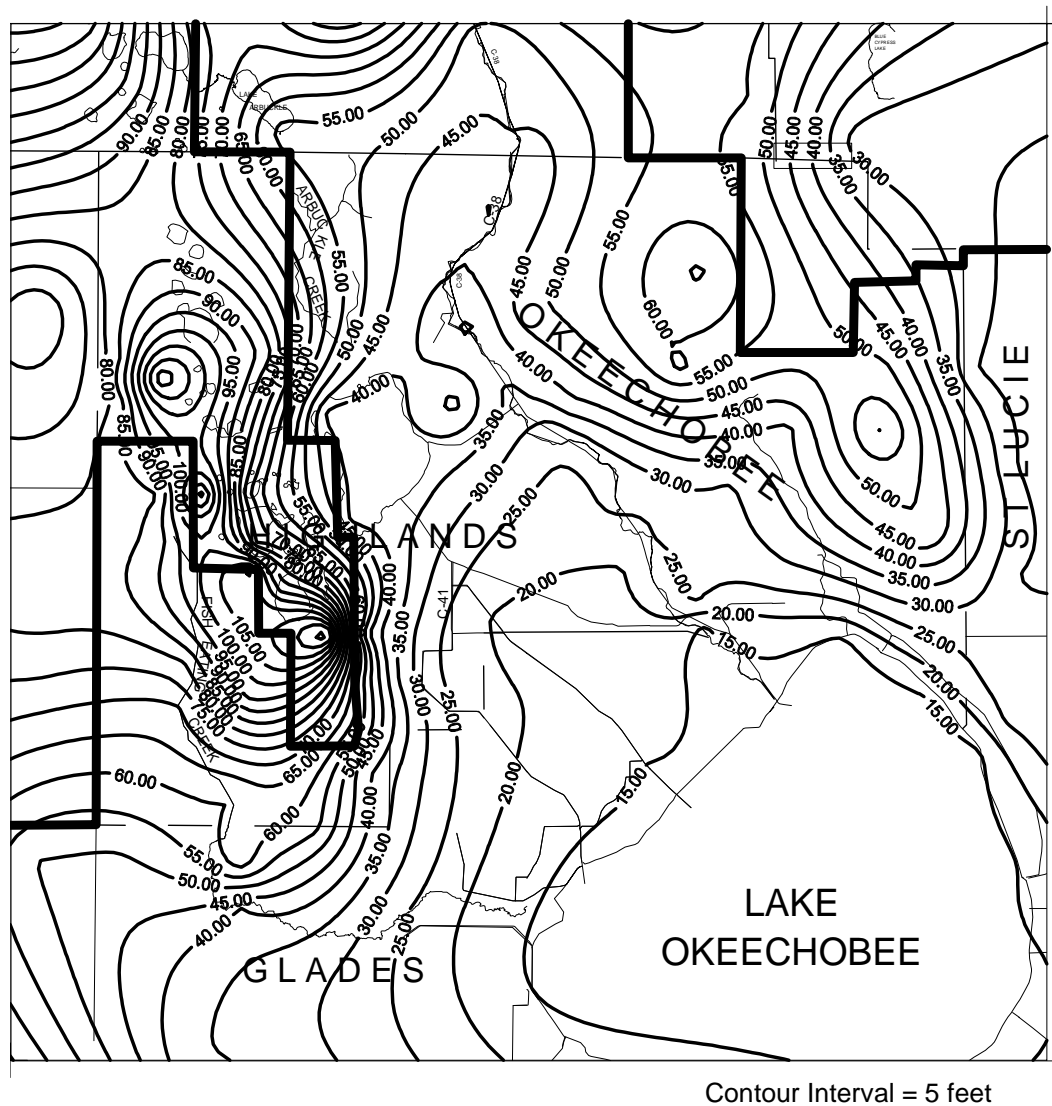
Contour Interval = 5 feet

Figure H-15. Constant Head Values for Layer 1 (Water Table Elevation).

An attempt was made to run the model with Layer 5 (LFA) as a fully active layer with constant heads along only the periphery of the model, however the model would not converge despite significant efforts at adjusting model parameters within reasonable ranges. The algorithms used for ground water flow models are designed to mimic water movement through a porous media. The conduit (pipe-like) type flow present in the LFA likely allows for faster movement of water over longer distances than the model algorithms (Darcian-flow based) allow. It is believed that this is the reason the model did not converge with Layer 5 as a fully active variable head layer.

The Floridan model of St. Lucie and Martin counties (Lukasiewicz, 1992) that was previously developed by the SFWMD experienced similar difficulties. The only workable solution to this non-convergence is to make layer 5 a constant head layer. Conceptually this is appropriate, making Layer 5 a constant head layer allows the model to provide, or remove more water. This is exactly the effect that the conduit flow present in the natural system has.

Water level data for the LFA was extremely sparse, therefore these levels were estimated based on the relationship between the UFA and the LFA water levels observed at the few locations where this data was available. After correcting for the effects of variable water density in the wellbores related to variable water quality from the different aquifers, two distinct relationships were observed. In known UFA recharge areas, water levels in the UFA were approximately two feet higher than levels in the LFA. In known discharge areas, water levels in the LFA were approximately two feet higher than the levels in the UFA. These relationships were applied using water levels from the UFA to develop the constant head matrix for the LFA. Conceptually this method can be explained by the semi-permeable nature of the MCU unit that separates the LFA from the UFA. This approach was also applied by Lukasiewicz (1992) and Tibbals (1990) in their previous models. All Floridan water level measurements were used as corrected head levels to remove any density affect on water levels. Higher levels of dissolved minerals can slightly increase the density of the water, which can suppress the water levels.

Ground Water Use Estimates

As part of the 1995 model calibration effort and again for the future water use simulations, water use estimates were developed for entry into the constructed model. Development of the 1995 and the 2020 water use databases were compiled as urban and agricultural components to ease calculation. Urban use includes public water supply, landscape irrigation, golf course use, and commercial/industrial uses. Agricultural uses include crop irrigation and all other associated agricultural activities. For the development of the 1995 urban use, actual water use records were utilized where available. The remaining uses were estimated using permitted water use values. Projections of urban water use growth were made based upon U.S. Bureau of the Census and the Bureau of Economic and Business Research population projections. Commercial use and landscape increases were also estimated based upon the urban population growth.

Agricultural water use was addressed in a slightly different fashion. Estimates of 1995 crop acreage were based upon aerial photography that has been integrated into a GIS

database. The identified acreage was then combined with source code, irrigation system identification and well location information found in the SFWMD regulatory database. This information, along with soils and local rainfall records, were utilized to calculate supplemental irrigation requirements using a Blaney-Criddle based model. Areas located outside of existing permit boundaries were also identified and their estimated water use applied to the most common surrounding source. Projections of 2020 agricultural acreage were made using a combination of industry, IFAS, and local grower information to estimate growth in acres for each crop type. This revised acreage was then distributed among either existing permitted facilities or to areas identified though a specific IFAS study on citrus distribution in Highland County. Details on the methods of water use estimates and projections can be found in Appendix F of the KB Water Supply Plan.

The location and aquifer of ground water withdrawals was based upon information obtained in the regulatory database. Water use from outside the SFWMD was obtained from the SWFMWD who has maintained an annual water use survey since 1990. Similar information was also obtained from SJRWMD for the eastern portions of the modeled area that are within the SJRWMD. An estimated 2,482 wells were incorporated into the model.

Calibration

Calibration is the process of adjusting parameters of a numeric model so that the model results closely approximate observed values. The GOH model was calibrated to steady-state conditions. Due to time, personnel, and fiscal constraints, a transient calibration was not performed. Steady-state can be viewed as an average condition achieved over a long period of time. It presumes that no major changes in stress rates occur during the time period.

Because of land access difficulties, personnel and budget constraints during the data collection process, the amount of water level data available for the FAS calibration was limited to 50 wells. The requirement to expand the model into Glades and Highlands counties took place after the data collection phase. Therefore, most of the data that was used in these two counties was not collected specifically for the model. Many of the FAS wells in these areas had only one wet and one dry season measurement per year.

The limited data available for these calibration points limits the calibration procedures. It was not possible to statistically evaluate water level elevations for the FAS wells as was done in the Osceola model. Calculated water levels were compared to observed water levels for the for the Osceola model, and one of the calibration checks involved determining if the calculated water level value was within one standard deviation of the measured value. The limited number of measurements from most of the FAS wells in the GOH model was not adequate for determining standard deviations for these wells consequently this type of calibration check could not be performed.

Water Level Calibration

Three criteria were used to assess if the model was in calibration:

1. Comparison of calculated to measured steady-state water level. At least 50 percent of the calculated averaged water levels should be within two feet of the calculated water levels at the same location.

2. Calculated recharge and discharge areas should correspond with known recharge and discharge areas.

3. The model generated contour map for the FAS (steady-state) should approximate the contour map generated from the average of the observed FAS water levels for the same period (1995).

The model was calibrated by comparing calculated levels from Layer 3 (UFA) to measured water levels. Average values for measured water levels from 50 monitor wells (1995 data) were compared to calculated water levels at the same locations. The differences between the two values, known as a residual, demonstrates how well the model is calibrated. Initial review of the residuals showed a clustering of high residuals along the Lake Wales Ridge indicating that the model was not well calibrated in this area. In some areas along the ridge, the calculated values were higher than the observed values. In other areas along the ridge, the observed values were higher than the calculated values.

A review of model input parameters revealed that the high residuals along the ridge were likely due to insufficient detail in the constant heads for Layer 1, the SAS, in the Lake Wales Ridge area. The ridge area has significantly more topographic relief than the other areas of the model. This topographic relief, in turn, allows for greater variability in SAS water level elevations. Water level elevation of the SAS (especially relative to FAS water levels) is one of the primary driving forces for recharge/discharge to and from the FAS.

After the high residuals in the ridge area were noted, more detail and accuracy was added to the constant head values used in Layer 1. This improvement in the constant head values for Layer 1 significantly reduced the residuals.

Many of the parameters used for the model development, especially the geologic parameters, are not exact in nature and values are often expressed in ranges. This is due to the heterogeneity of the material, the variable interpretation of some of the testing methodologies and variability of results due to the scale of measurement that is used. For instance, laboratory tests of permeability likely will not accurately account for secondary permeability.

Because of the fact that many parameters are not known precisely, it is possible in the calibration process to go back and modify any of several different model input parameters such as vertical conductivity of a given layer to try to obtain a lower residual. This type of "tweaking" of model parameters to get a better calibration might generate a model that appears to be highly accurate while in reality the model may not represent or predict the natural system any better than the earlier "non-tweaked" version of the model. For this reason, tweaking of the model to obtain lower residuals on a well by well basis was not done based solely on the residual value. However, if a high residual was noted at

a well, the model and data sets were reviewed to determine the reason for the high residual. In some cases it was possible to determine what might be accounting for the high residual value, and improvements could be made to model parameters or data. An example of this was the improved accuracy and detail in the constant heads for the SAS.

    Table H-4 lists the calibration results for the UFA. **Table H-5** provides summary statistics for the calibration results.

Table H-4. Calibration Results, GOH Model Layer 3, UFA.

Station Name	Model Layer	Observed Water Level	Computed Water Level	Residual
OK-1	3	41.74	44.12	-2.38
OKF-7	3	45.46	46.91	-1.45
OKF-9	3	46.03	48.48	-2.45
OKF-17	3	44.97	46.33	-1.36
OKF-18	3	46.33	48.40	-2.07
OKF-23	3	42.34	44.71	-2.37
OKF-25	3	47.04	47.14	-0.10
OKF-31	3	48.52	47.42	1.10
OKF-40	3	43.97	45.95	-1.98
OKF-53	3	38.65	42.25	-3.60
OKF-54	3	38.58	41.66	-3.08
OKF-56	3	47.42	47.48	-0.06
COOK	3	40.61	42.35	-1.74
MAXCYJ-1	3	37.90	39.96	-2.06
OKF-74	3	41.00	40.18	0.82
OKF-34	3	45.60	48.12	-2.52
OKF-81	3	43.83	46.15	-2.32
OKF-82P	3	40.77	42.43	-1.66
OKF-89	3	43.96	44.55	-0.59
OKF-94	3	44.21	45.99	-1.78
OKF-96W1	3	44.92	48.13	-3.21
HIF-3	3	51.79	49.79	2.00
HIF-4	3	46.39	44.80	1.59
HIF-5	3	47.23	52.77	-5.54
HIF-8	3	45.54	51.46	-5.92
HIF-13	3	47.03	48.36	-1.33
HIF-14	3	47.72	50.03	-2.31
HIF-16	3	62.86	64.69	-1.83
HIF-26	3	48.80	50.31	-1.51
HIF-37	3	45.76	46.75	-0.99
LYKESBRO	3	47.00	45.66	1.34
IR-373	3	38.00	39.06	-1.06
GL-155	3	47.35	47.20	0.15
PALMDALE	3	49.80	50.63	-0.83
ROMP28F	3	65.85	64.37	1.48
ROMP43F	3	81.43	79.85	1.58
729114	3	46.39	44.80	1.59
73111501	3	51.79	49.79	2.00
Dresslers	3	78.10	78.26	-0.16
PRAIREOA	3	68.45	72.58	-4.13
NARANATHA	3	78.11	78.14	-0.03
CTYSEBRI	3	75.87	78.12	-2.25
JOHNMCCU	3	75.54	76.81	-1.27
BONNETLK	3	75.96	77.99	-2.03
FLOYD	3	79.37	79.62	-0.25
ROBERTRI	3	73.69	75.12	-1.43
CLENNY	3	75.45	77.26	-1.81
OSF-42	3	44.23	46.34	-2.11
OSF-60	3	40.63	43.29	-2.66
S65-A	3	44.98	47.10	-2.12

Table H-5. Summary Statistics for Calibration.

Residual Mean	-1.29
Res. Std. Dev.	1.76
Sum of Squares	239.43
Abs. Res. Mean	1.84
Min. Residual	-5.92
Max. Residual	2.00
Head Range	43.53
Head Range/Std	0.04

Model Results

After the model was calibrated to 1995 average water level data, the 1995 well pumpage data sets were replaced with estimates of well pumpage for the year 2020 under average conditions, and later by data sets of estimated 2020 well pumpage in a 1-in-10 year drought scenario.

The 2020 public water supply well pumpage estimates were generated by applying the 1995 per capita water usage to population projections from the U.S. Census and the KB Water Supply Plan population and land use projections for the year 2020. The 1995 agricultural water usage was generated by estimating agricultural acreage from satellite imagery and then multiplying the acreage for a given crop type by the irrigation demand as estimated from the Modified Blainey Criddle Formula.   The 2020 agricultural use was estimated by contacting the county agricultural extension offices to obtain projections of crop acreage changes for the year 2020 and again using the Modified Blainey Criddle Formula to estimate irrigation demand.

The model was run under each of the 2020 well pumpage scenarios and the resultant UFA potentiometric surface levels were compared to the levels generated from the 1995 well pumpage files. Maps showing the changes in the potentiometric surface of the UFA were then generated from this comparison to show where, and by how much the UFA water level may be impacted by increased withdrawals.

Figure H-16 is a three-dimensional contour map depicting the top of the potentiometric surface for the UFA generated from measurements taken in 1993. The potentiometric surface depicted in this map is very similar to the two dimensional potentiometric surface maps shown in **Figure 18** and is intended to assist the reader in visualizing the UFA potentiometric surface. The map clearly shows the mounding of the aquifer beneath the primary recharge areas in the northeastern portion of the model area. The recharge area is the topographic highs along the Lake Wales Ridge and areas extending to the north into Polk County. These topographic highs coincide with areas where the confining units above the UFA are thinner, more permeable, and frequently

breached by sinkholes. These factors allow surface water and SAS water to more easily recharge the UFA in these areas.

Figure H-17, an east to west head profile passing through Lake Istokpoga along row 55 of the GOH model, shows the head levels for all five layers across the profile. Areas of recharge to the UFA area characterized by head levels in the surficial aquifer that are higher than UFA head levels, distance levels less than 90,000 on the plot and also in the range of 270,000 to 290,000. The western (left) recharge area in the plot corresponds with the Lake Wales Ridge, while the eastern recharge area corresponds with the topographic high associated with the Penholoway Terrace.

The low, 30-foot water levels for the SAS at around the 200,000 mark in the center of the graphic corresponds with the Kissimmee River floodplain. The dip in UFA water levels at the 160,000 thousand distance mark is related to UFA withdrawal by agricultural wells.

Figure H-18 depicts the potentiometric surface of the UFA as generated from the calibrated model using 1995 pumpage data sets. Based on this map, and the well pumpage data sets, it is possible to determine the affect on the potentiometric surface due to well withdrawals. There appears to be three areas where withdrawals have had a measurable, though not significant, effect on the UFA. Eastern Highlands County and northeastern Glades County have several depressions in the surface of the UFA. Northwestern Glades and southwestern Highlands counties, as well as western St. Lucie County also show slight depressions in the surface of the UFA related to agricultural withdrawal of water from the UFA. **Figure H-19** shows the surface of the UFA under average conditions in the year 2020. **Figure H-20** shows the UFA surface as it is likely to appear based on increased UFA withdrawals during a 1-in-10 year drought event. (As mentioned earlier, this scenario does not account for the decreased recharge from the surficial aquifer that is likely to occur during a drought event).

It is difficult to visualize the change in head from 1995 to 2020 by looking at **Figures H-18** through **H-20**. In order to more clearly show the change in UFA head, figures 11 and 12 were generated. **Figure H-21** shows the change in head (due to UFA pumpage) from 1995 to 2020 average conditions, while **Figure H-22** shows the change in head (due to UFA pumpage) from 1995 to 2020 under a 1-in-10 year drought situation. Note that the contours on these last two figures are in two-foot increments, while the contours on the previous maps were in five-foot increments.

Figure H-21, change from 1995 to 2020 average conditions, shows that the area most affected by increased withdrawals is the eastern Highlands and northeastern Glades areas that were already affected in 1995. **Figure H-22**, change from 1995 to 2020 1-in-10 year drought, shows similar effects, with some additional areas showing increased drawdowns. These additional areas are in southeastern Highlands and eastern Okeechobee counties.

These impacts do not appear to be significant, and will likely cause no hardships on other UFA users. Most of the withdrawal wells in these areas are located on large
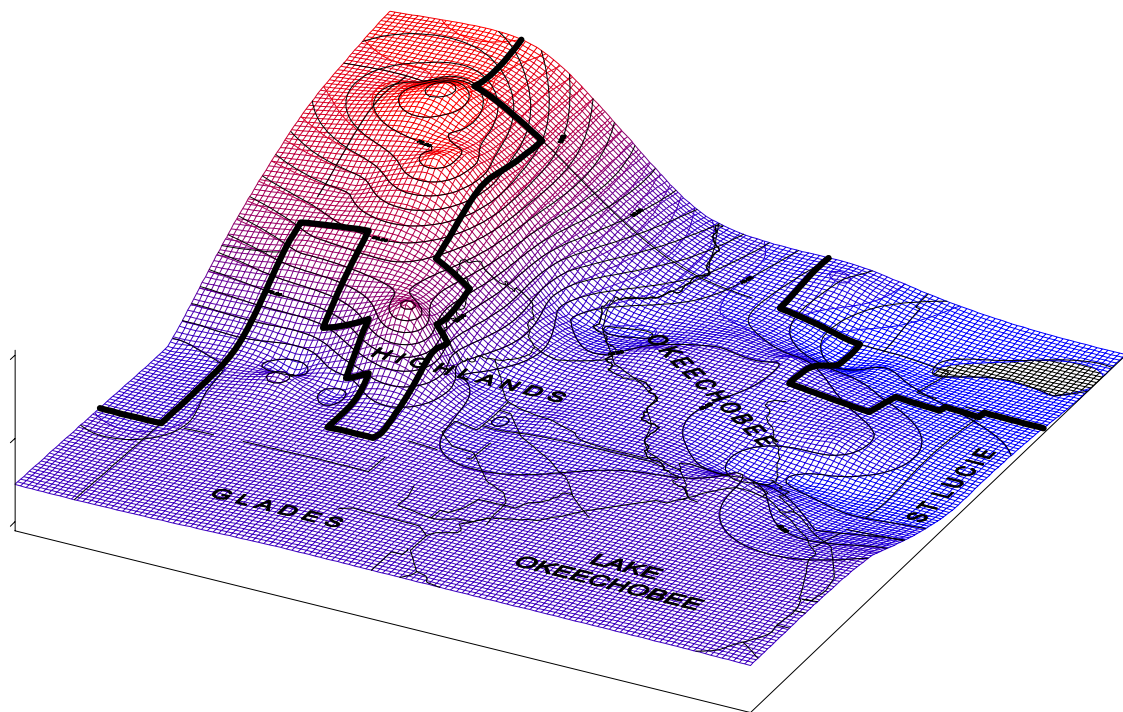
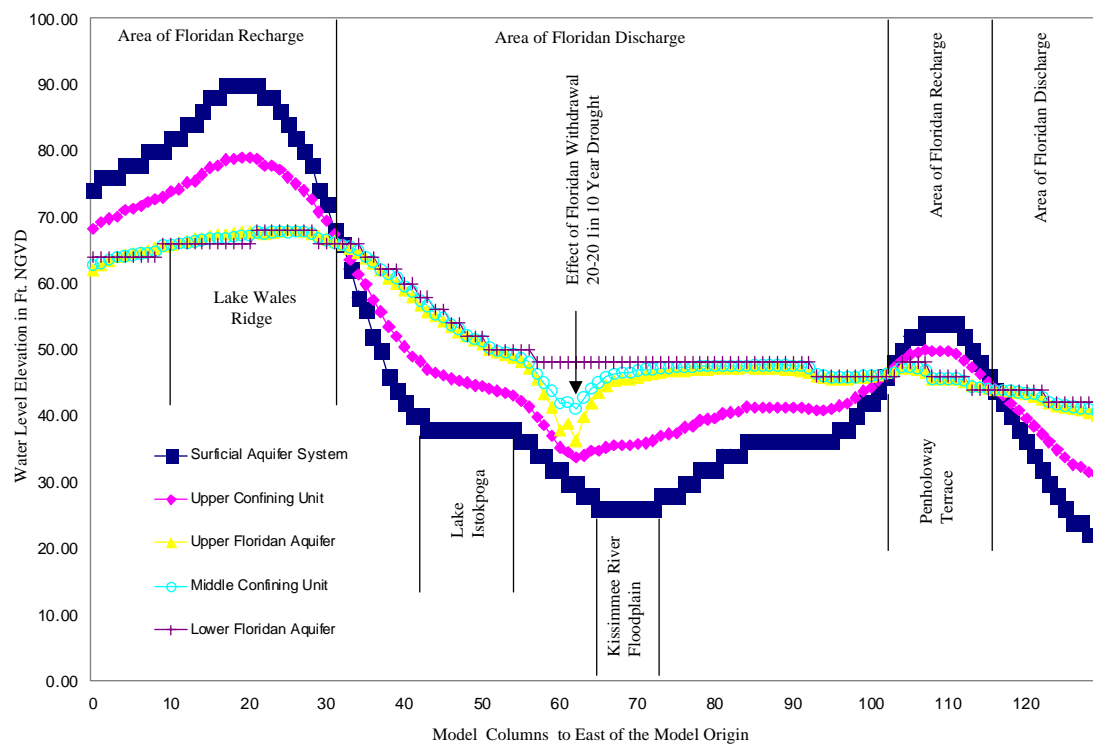**Figure H-16.** Potentiometric Surface of the Upper Floridan Aquifer.

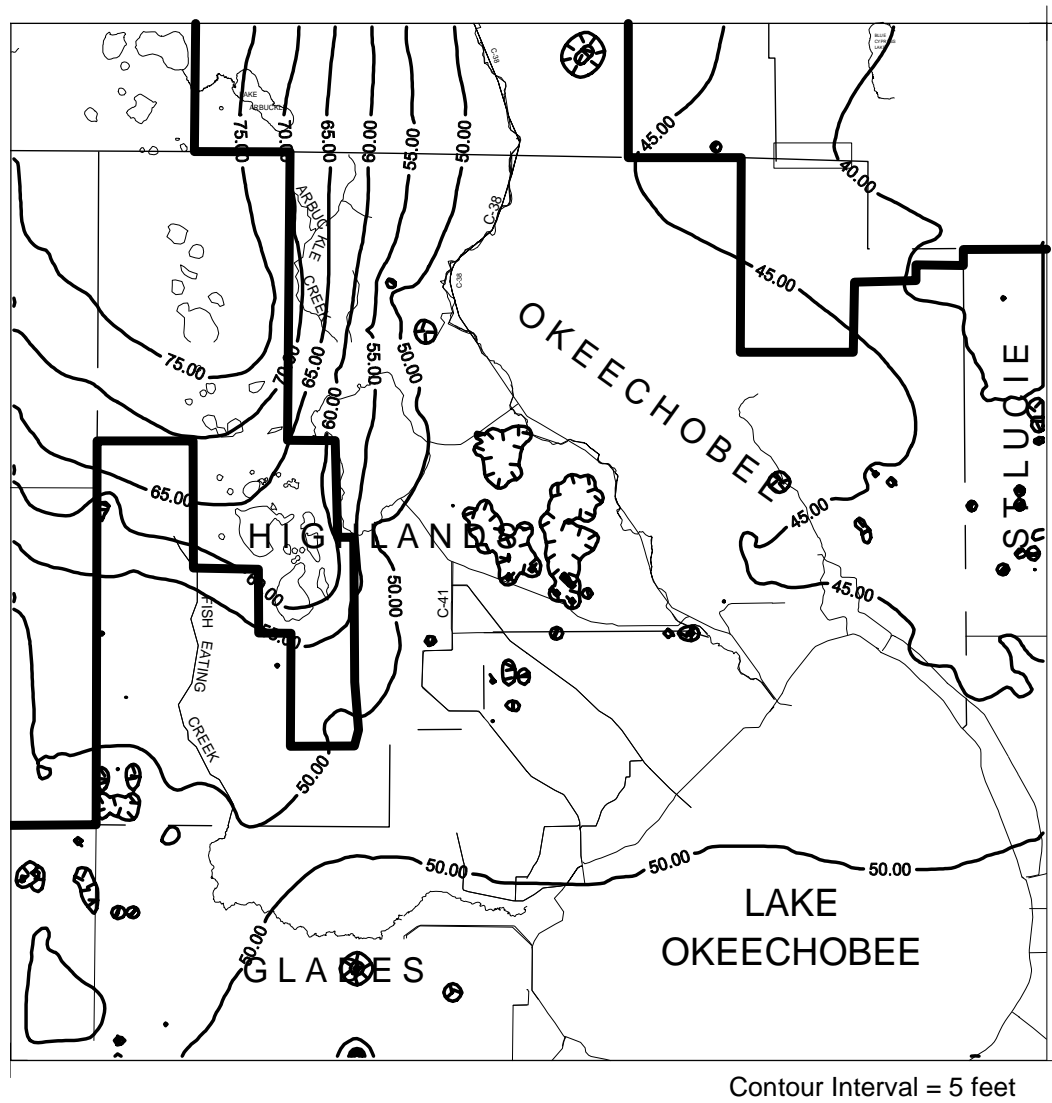**Figure H-17.** East to West Head Profile Passing through Lake Istokpoga.

Contour Interval = 5 feet

Figure H-18. Potentiometric Surface of the UFA as Generated from the Calibrated Model Using 1995 Pumpage Data Sets.

Contour Interval = 5 feet
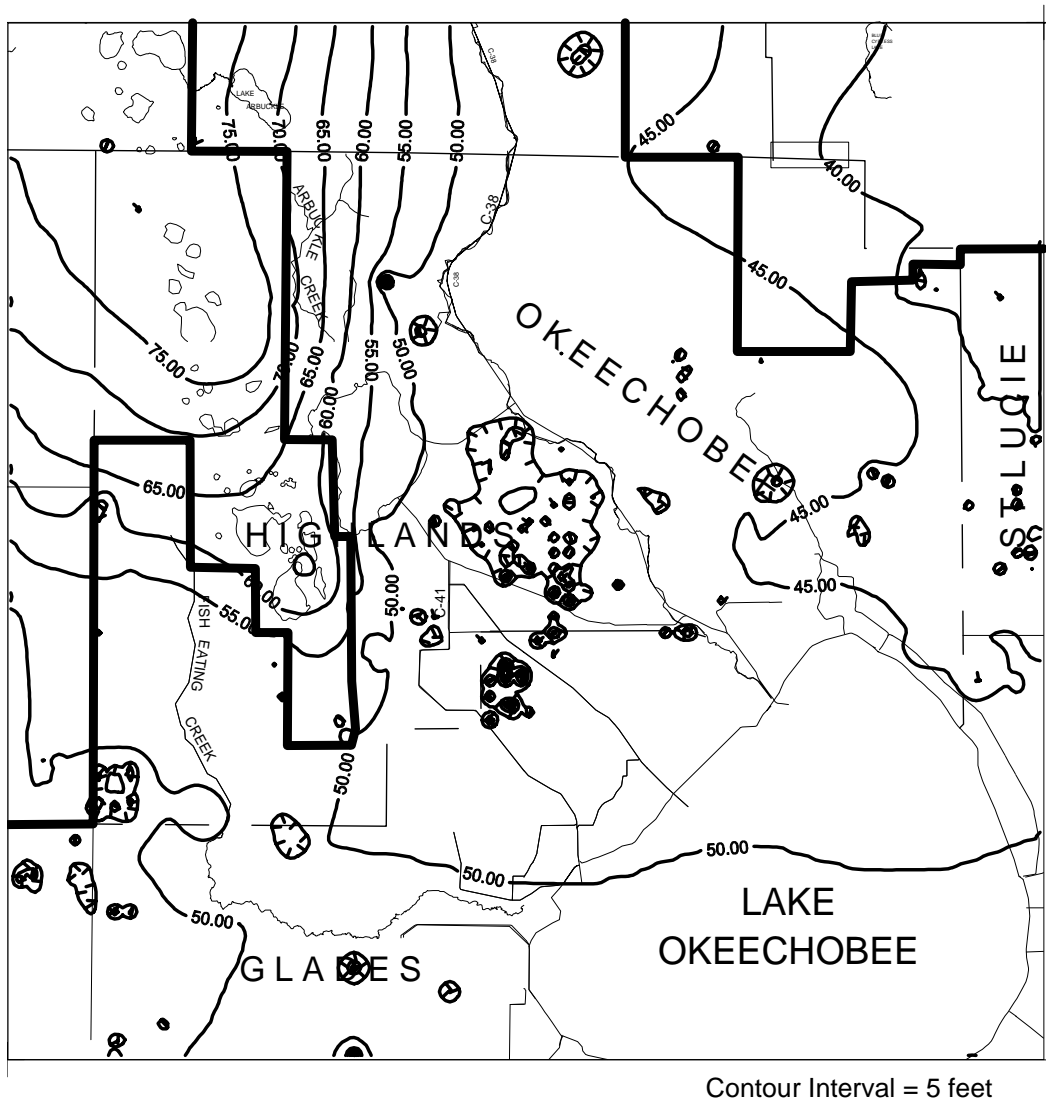
Figure H-19. Surface of the UFA under Average Conditions in the Year 2020.

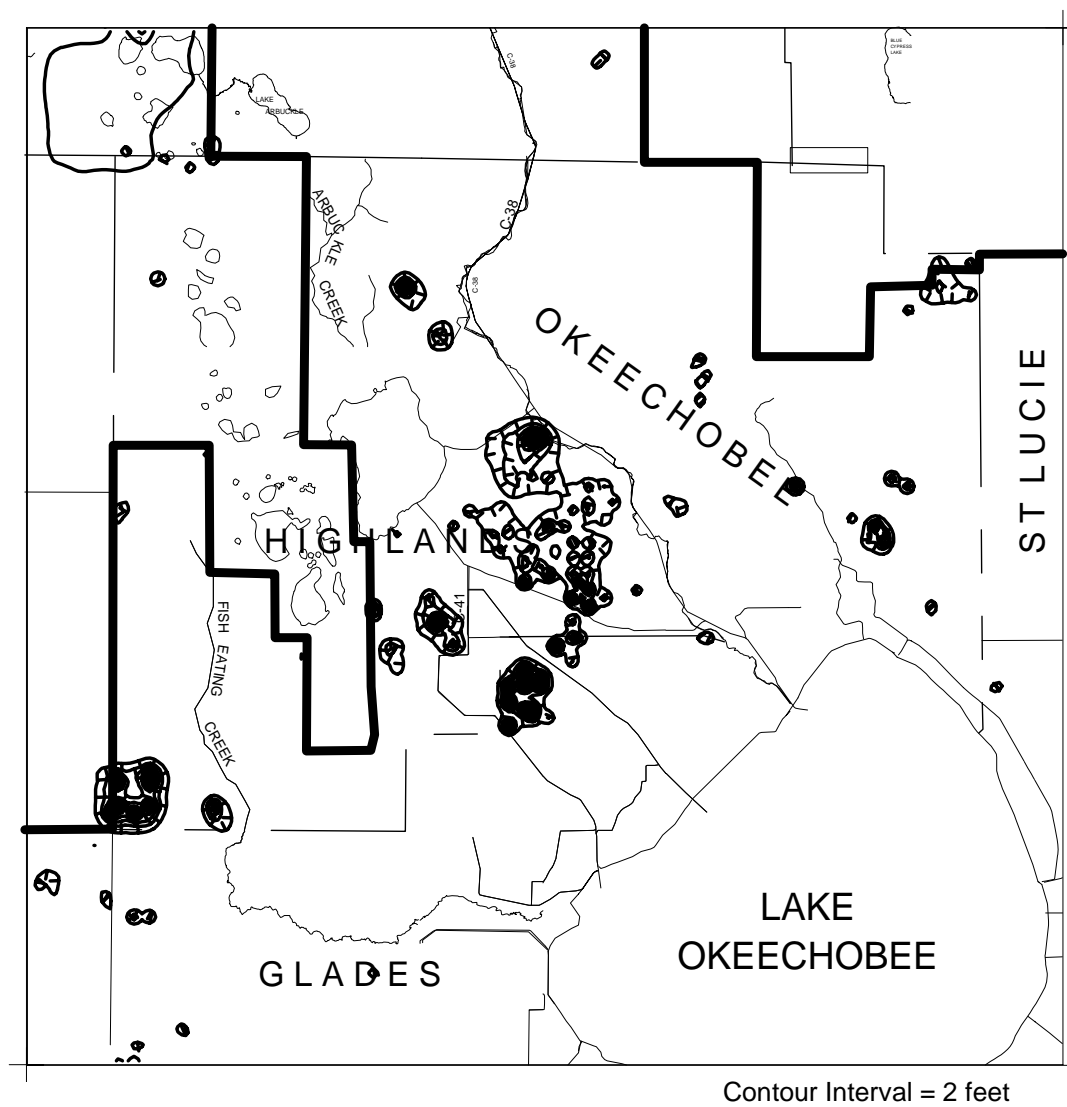Contour Interval = 5 feet
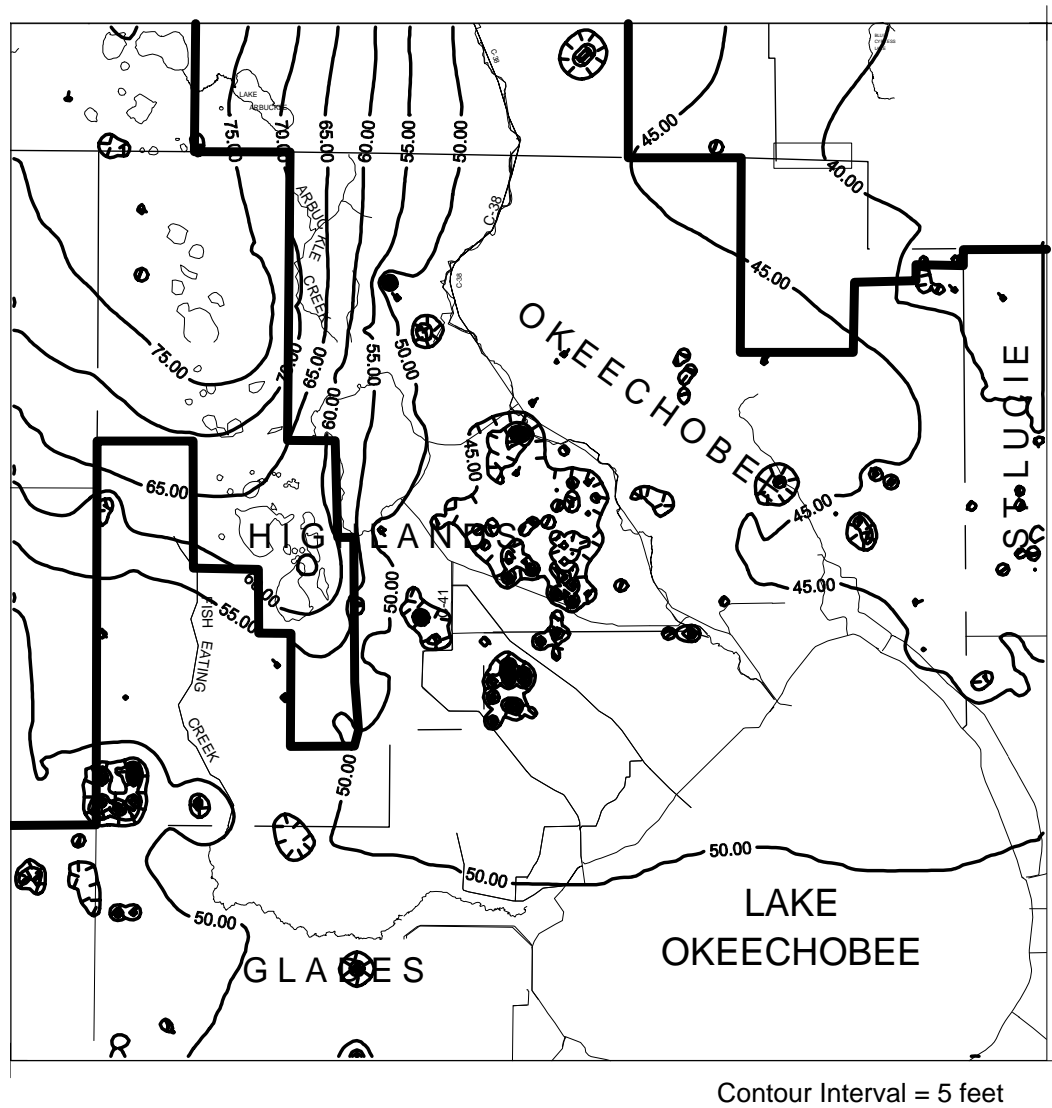
Figure H-20. UFA Surface Based on Increased UFA Withdraws during a 1-in-10 Drought Event.
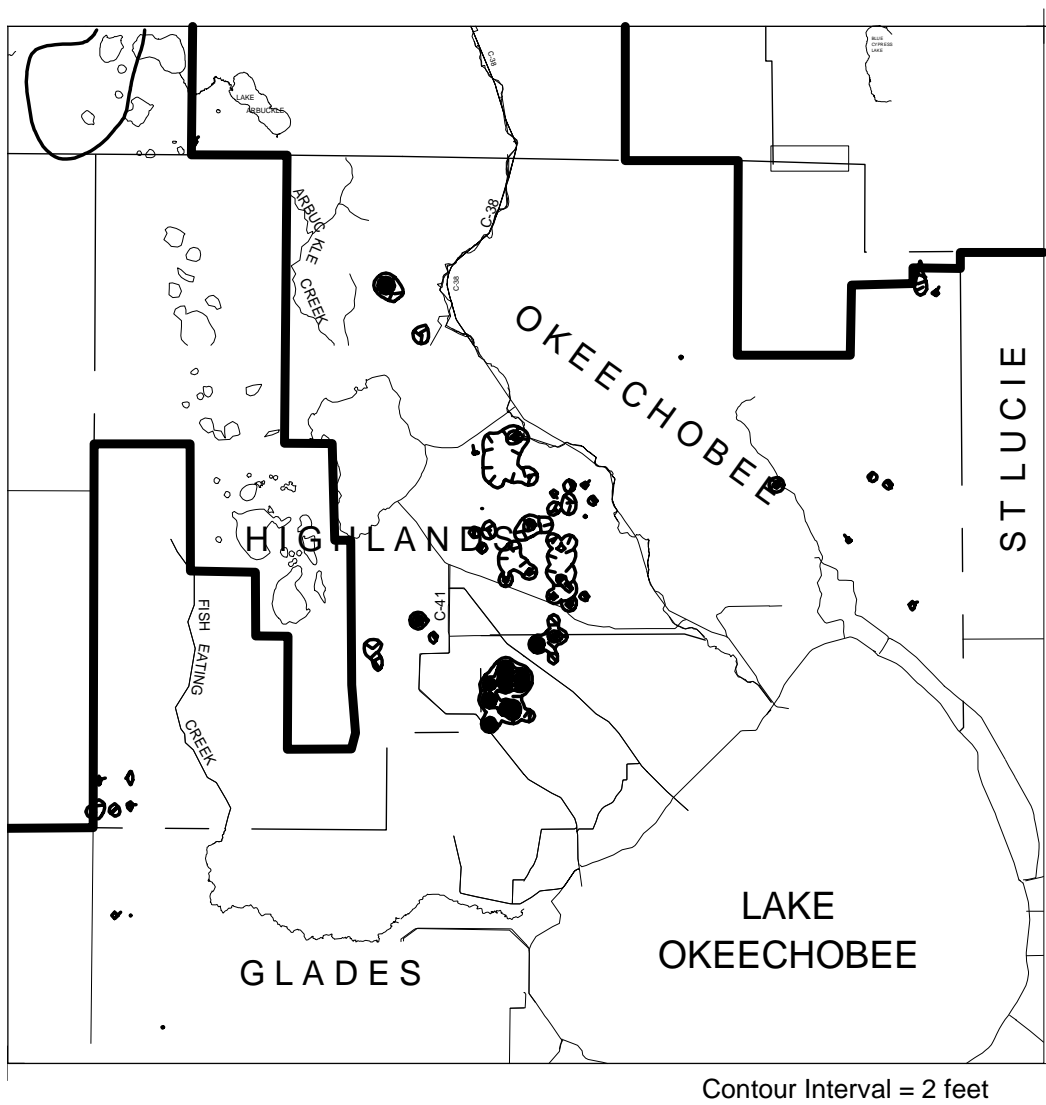
Contour Interval = 2 feet

Areas enclosed by contours indicate a decline in Floridan Water Levels of
two or more feet.

Figure H-21. Change from 1995 to 2020 Average Conditions.

Contour Interval = 2 feet

Areas enclosed by contours indicate a decline in Floridan Water Levels of two or more feet.

Figure H-22. Change from 1995 to 2020 1-in-10 Year Drought Conditions.

parcels of agricultural properties. Therefore, it is unlikely that off-property impacts would be noticeable to other UFA users. Also, because most of these impacts are in areas of artesian flow and the aquifer is over three hundred feet deep, there is no possibility of wells going dry. The worst possible impact even in these most impacted areas would likely be only slightly decreased natural flow from artesian wells near areas of major withdrawal.

Summary and Conclusions

The GOH model development shows that the current level of usage from the Floridan aquifer in the GOH model area does not appear to be detrimentally impacting the FAS. There are no areas of significant water level depression due to current groundwater withdrawal. The areas where there were cones of depression due to Floridan aquifer withdrawals were generally limited in extent and the amount of drawdown. The Floridan aquifer impacts in the modeled area appear to be less than in other areas of central/south Florida. This is due to the relatively low Floridan water usage (current and projected) as compared to the other areas.

The year 2020 average conditions and 2020 1 in 10-year drought projections indicate that the changes due to pumpage will be limited to only moderate increases in the extent and depth of the current cones of depression. The model indicates that the projected Floridan aquifer withdrawals for the year 2020 should not impact surface water bodies such as the lakes located on the Lake Wales Ridge. This is of course contingent upon the accuracy of water use projections. Also one very important factor to consider is that the model projections for the one in ten year drought are only for the increased drawdown due to increased well pumpage. These projections do not take into account the decreased recharge to the Floridan aquifer during a drought and the possibly increased upward leakance in areas of discharge due to lower "suppression" heads in the overlying strata. Any decline in water levels due to these factors would have an additive impact in addition to the impact from well withdrawals.

The model runs that were made did not attempt to allow for the possible decreased upward leakance due to the increased water levels in the SAS near the Kissimmee River due to the Kissimmee River Restoration project. Because Layer 1 (the SAS) is not active, it is not possible for the model to estimate the impact of the restoration on the UFA.

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